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CATALOGUE

OF THE

MECHANICAL ENGINEERING COLLECTION

IN THE

SCIENCE MUSEUM,

SOUTH KENSINGTON.

WITH DESCRIPTIVE AND HISTORICAL NOTES.

PART I.

STEAM ENGINES AND OTHER MOTORS;
LOCOMOTIVES AND RAILWAYS;
MECHANICAL MEASURING APPLIANCES;
PUMPS AND LIFTING MACHINERY;
POWER TRANSMISSION.

Sixth Edition, Revised, with a Supplement containing illustrations.

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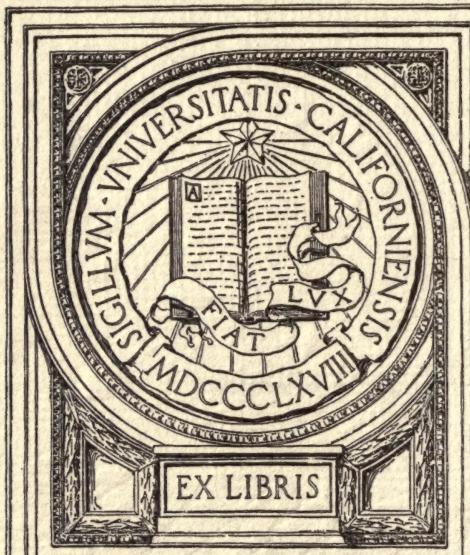

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PREFACE.

THIS Collection was commenced in 1867, by direction of the Lords of the Committee of Council on Education, with the view of affording in the best possible manner information and instruction on the immense variety of machinery in use in the manufactures of this country. A very valuable addition, consisting of models made by James Watt himself, or his workmen, was in 1876 presented to the Museum by Messrs. James Watt & Co. A further large accession of machines and models was received from the Patent Office Museum when, in 1884, under the Patent Law Amendment Act, that Museum was discontinued and its collection was handed over to the Science and Art Department, now merged in the Board of Education. From time to time purchases of particularly interesting objects have been made, but to a very large extent the Collection has been assisted by gifts and loans of machinery, models, and drawings from manufacturers and inventors, and it continues to rely mainly upon such sources for its augmentation.

It is not the object of the Collection to attempt to indicate the present state of the arts in any particular branch of engineering. Its aim is rather to illustrate broadly the steps by which advances have been made up to the present day; to show students and others at the same time the general principles which underlie all its branches, and to offer to the engineer suggestions or ideas from other branches of his profession that may prove fruitful in the work upon which he may be engaged.

Many of the machines are shown in motion daily from 11 a.m. till closing time, the motive power being supplied by a compressed air service. Where practicable, these objects are fitted with self-closing air-valves, by means of which visitors may start them at will. Other objects are arranged so that visitors may work them by turning a handle or by other means, and there are a few that can be shown in motion only by an attendant.

The Sections of the Collection relating to Electrical Engineering have been excluded from this Edition of the Catalogue owing to their transference to the Western Hall, where they could be grouped with other objects there relating to Electricity.

The greater number of the objects in the Mechanical Engineering Collection have been photographed. Particulars of prints and lantern slides that are available may be obtained on personal application at the Sale Stall at the Museum, or by letter addressed to "The Secretary, The Science Museum, South Kensington, S.W.7."

*** *In the Science Library of the Museum there is a complete series of Specifications of the Patent Office, from A.D.* 1617 *onward, which may be consulted free.*

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PART I.

Numerical references in the text refer not to the page but to the serial numbers placed at the beginning of each catalogue title. When an object is illustrated the reference to the plate of illustrations (bound separately) is given immediately after the title. The number at the termination of each description is that under which the object is registered in the Museum.

MOTORS OTHER THAN HEAT ENGINES.

Till the period of the invention of the steam engine, the industrial work of the world was done by harnessing those obvious sources of power: animals, wind, and water. Of these, the first-named performed the greatest share. The water-wheel, although less fluctuating and more compact than the windmill, suffers from limitation of site, accounting for the distribution of these two types observable in hilly and in flat countries respectively.

Animal Power.—Although as a motor an animal is possibly a heat engine, its cycle is complex and outside the scope of the engineer, so that reference is made here to those mechanisms only by which the work done is transformed into convenient forms.

A man in rowing, in walking up a ladder or on a treadmill, can exert his strength to the best advantage; turning a crank handle is a more convenient but less efficient method. By the

latter means a man can perform in an 8-hour day work at the rate of from 2,200 to 3,300 ft. lb. per min. (*i.e.*, 0·06 to 0·1 h.p.). For a minute or two he can work at about eight times this rate, after which he must rest for a considerable time. A horse works to greatest advantage when pulling horizontally at a speed of about 2·5 m.p.h., when in an 8-hour day it can work at the rate of from 22,000 to 33,000 ft. lb. per min. For driving machinery some form of horse gear or gin (*see* Nos. 2, 3 & 4) is required; on a circular track the work obtainable is only from 16,000 to 26,000 ft. lb. per min. An ox in a gin works best at half the speed of a horse, but will do 16,000 ft. lb. per min.

Windmills.—While the power of the wind is probably the form of energy that was utilised earliest by man, *i.e.*, in the propulsion of ships, its application to industrial uses, *e.g.*, for grinding corn, does not appear to have been known in Mediterranean lands before the Christian era, while the first authenticated instance of its use in this country was in the year 1191. This was the crude apparatus known as a post-mill, in which a wooden building supporting the sails and shaft and containing the gearing and millstone is free to turn on a vertical post, for the purpose of bringing the sails into the wind. To do this, a pole projecting from the building nearly to the ground was provided. As the length of the sails increased, the post gave place to a more stable masonry tower upon which the top of the building could rotate on rollers; this improvement is believed to be due to Dutch engineers of the 16th century. The sail-shaft was geared into a vertical shaft on the axis of rotation, and carried at its lower end a spur wheel into which geared four or a less number of pinions each carrying a millstone, the total ratio of gearing being about 1 : 12. As the size and height of mills further increased, better means for rotating the top were needed. Early in the 18th century a fan-wheel, in a plane at right angles to that in which the sails revolve, was added; by gearing on the tower the top was turned by the fan till it ceased to revolve (*i.e.*, with its edge to the wind). Other improvements consisted in governing, reefing the sails, etc. (*see* Nos. 5–7). Smeaton in 1759 communicated to the Royal Society results of his investigations as to the speed, proportions and weathering angles of sails.

As the pressure of wind on a plane surface varies as the square of the velocity, the power must vary as the cube, assuming the speed of the sail proportional to that of the wind. This is found to be practically true, so that it is explained why the power falls off so rapidly as the wind drops. The power developed by a windmill is small, say from 4 to 20 h.p., and is small also relative to its cost.

In recent years a smaller and lighter type of mill has come into use, particularly for raising water. In this the place of the sails is taken by a disc, 6 to 30 ft. diam. or more, made up of a number of narrow vanes or slats. This is mounted on a light steel or wooden tower and the pump-rod, etc., is worked by transmission mechanism directly from the wheel spindle. Besides automatic devices for turning them into the wind, these wheels have self-regulating vanes to enable them to withstand a gale

without attention. In one type the vanes turn on their axes as the wind pressure increases (*see* Nos. 6 & 7); in another the wheel is unbalanced so that the wind tends to turn it edgeways; while in a third the disc closes somewhat after the fashion of an umbrella.

Attempts have been made by Blyth and Rollason, with some measure of success, to construct a windmill to work on a vertical axis and thus be independent of the direction of the wind.

Water-wheels.—The application of a water-wheel to give motion to millstones is mentioned by Strabo, the geographer, as having been made about 70 B.C. These were what is known as current wheels, as exemplified in the Persian wheel (*see* No. 607), used for raising water and in the floating corn mills on the Tiber and other rivers. If water under a slight head is delivered to the wheel it is known as undershot. The efficiency of this wheel is greatly increased if constructed according to the principles of Poncelet (*see* No. 12). In all these types the water acts mainly by impulse, but there are other types in which it acts by gravity. If the available fall is sufficient the water can be projected over the summit of the wheel, which is then known as overshot. If a moderate fall is available, the wheel is proportioned so that the water comes on above the axis, when it is known as a breast-wheel (*see* No. 11). The exact shape of the buckets is important, as they must be open enough to receive the water quickly and yet so shaped as not to spill it too soon.

Hydraulic Turbines.—The name turbine was originally applied to any water-motor which revolved on a vertical axis. The first impetus in the development of such motors was given in 1827 by the Société d'Encouragement, who offered a prize for an improved form, ultimately won by Benoît Fourneyron (b. 1802, d. 1867). No hard-and-fast line can be drawn between the turbine and the water-wheel, but the former consists essentially of a wheel provided with a number of vanes or blades through or upon which the working fluid is directed. Turbines can take advantage of high falls quite beyond the limits of water-wheels, and even at low falls the efficiency of the turbine is greater *pari passu* than that of the water-wheel, which in consequence is practically obsolete.

Turbines are classified as (*a*) impulse or action, and (*b*) pressure or reaction, according as the whole or only a part of the available energy of the fluid is converted into kinetic energy before acting on the moving wheel. In case (*a*) the wheel passages are only partially filled with water and the wheel is situated above the tail race. In case (*b*) the passages are "drowned," and the wheel is generally below tail water level. Both (*a*) and (*b*) are sub-divided constructionally according as the flow of the working fluid is (1) radial, further sub-divided into inward and outward; (2) parallel with the axis, and (3) a combination of the two last known as mixed.

The simple form of the impulse turbine is the Pelton wheel (*see* Nos. 13 & 14), whose development from an ancient apparatus analogous to the undershot wheel can be traced. Governing gear has rendered the Pelton wheel suitable for very varying loads

(*see* Nos. 15 & 22). The advantage of the impulse or Girard turbine, so named after its inventor L. D. Girard, is the ease with which the water can be regulated with variable load without reducing the efficiency, a matter of difficulty in the pressure type. Fourneyron sub-divided his wheel horizontally, a method extensively used (*see* No. 16). Thomson in his vortex turbine (*see* No. 19) adopted movable guide blades.

The simplest form of the pressure or reaction turbine is the well-known but inefficient mill introduced by Dr. Barker in the 17th century (*see* No. 15A). Fourneyron invented the radial flow type in 1827, Jonval brought out the parallel flow type in 1841, while the mixed flow type is associated with the name of J. B. Francis about 1855.

Air and Water Pressure Motors.—The distribution of air under pressure was practically carried out by Murdock at Soho early in the 19th century, but the system has only received extensive application recently for portable tools (*see* No. 23). The distribution of hydraulic power introduced by Lord Armstrong in 1856 has led to the scheming of many forms of rams, such as the jigger, and of hydraulic engines (*see* Nos. 24–29). Successful attempts have been made to make use of the rise and fall of the tide (*see* No. 30), but on a large scale the practical difficulties are very great.

1. Model of tread mill: (Scale 1 : 12.) Made in the Museum, 1915.

The tread mill has been employed as an animal power prime mover from very early times, in a number of different forms, for such purposes as raising water, turning a spit, or as a means of punishment. The model represents the well-known mill at Carisbrooke Castle, Isle of Wight, as originally constructed; it is said to date from 1588, and is still in use for drawing water from the old well of the Castle.

The mill is an embodiment of the wheel and axle mechanism. The wheel or drum, which is of oak, has lagging fastened to felloes of natural-grown timber tongued and pinned together and tied back by arms tangential to the eight-squared axle where the latter are tightened by wedges; intermediate support to the felloes is given by timbers halved on the arms. The axle, which is a chestnut baulk about 14 in. diam., has iron gudgeons 2 in. diam. revolving on cast-iron pillow blocks supported by the walls of the well-house. The whole is a typical piece of medieval carpentry. A donkey walking inside actuates the wheel and raises a bucket of water by coiling a rope on the axle. There is a band brake now on the axle, but this is a modern addition; it is believed that originally the wheel was braked simply by a piece of wood held against the circumference.

The effective diameter of the wheel is 14·6 ft. and that of the axle, lagged where the rope coils on, is 21·5 in. In 1900 more lagging was put on, bringing the equivalent diameter up to 28·4 in.; the mechanical advantage, allowing for the thickness of the rope, has thus been altered from 7·4: 1 to 5·7: 1. The donkey causes the wheel to make four turns per min., *i.e.*, it walks at the rate of 2·08 miles an hour. When the bucket is going down the well, the wheel is allowed to rotate at about 20 turns per min. The well is 161 ft. deep, and from 16 to 20 turns of the wheel, according to the level at which the water is standing, are required to bring the bucket to the surface. The weight of the water raised is 120 lb.; taking into account the weight of the bucket, chain and rope, the h.p. is about 0·2, which is as much as a donkey is usually considered capable of doing.

(*See* "Engineering," 1915, ii., p. 260). Inv. 1915–317.

Horse Gears.

2. Model of horse gear. (Scale 1 : 8.) Lent by Messrs. J. L. Larkworthy & Co., 1891.

This shows a very general form of machine for applying the power of a horse to the driving of light machinery, such as chaff-cutters, small pumps, etc.; but although larger gears are made to transmit the power of two or four horses, they are not much used in this country when the power required approaches that of a small steam engine.

The machine has a pole attached to the vertical axis of a bevel wheel of 103 teeth, gearing into a bevel pinion of 12 teeth, whose rotation is transmitted by a shaft coupled by universal joints to multiplying spur gear placed outside the circular horse track. The multiplying gear consists of a spur wheel of 76 teeth driving a pinion of 17 teeth, to the shaft of which a pulley is attached for further transmitting the power by belting. The horse in going once round the track causes the pulley to make 38·3 rev., and when walking at 2·5 miles per hour in a path 25 ft. in diam., drives the pulley at 108 rev. per min. M.2385.

3. Horse gear. Lent by Messrs. J. Crowley & Co., 1888.

This is a small and compact form of gear patented in 1879 and intended for use with a pony. The slow speed of the vertical shaft turned by the animal is multiplied 30·2 times, so as to give higher speed to the horizontal shaft from which machinery is to be driven. To the bracket that holds the pole is attached a short horizontal shaft, carrying a bevel wheel of 31 teeth and a bevel pinion of 16 teeth. The pinion gears into a horizontal bevel ring that is stationary, and forms part of the framing. The bevel wheel gears with a bevel pinion of 22 teeth on a vertical axis in the centre, and this pinion carries with it a bevel wheel of 60 teeth that gears with a pinion of 16 teeth on the high-speed shaft. From this shaft the motion is transmitted through two Hooke's joints to the external driving pulley, a pawl gear preventing accidental rotation in the wrong direction. M.1958.

4. Model of inclined-plane horse gear. (Scale 1 : 5.) Made by Mons. J. Digeon, 1892.

A wooden platform, constructed as an endless belt, is supported on rollers, and at each extremity passes round a polygonal pulley. It is inclined at an angle of 13 deg., giving a rise of 1 in 4·5. The horse stands on the sloping platform, which is set in motion by the component of the horse's weight acting parallel to the platform, less the frictional losses, which are considerable. The horse's head is haltered to a bar in front, so that he is compelled to walk as the platform recedes (*see* No. 198). M.2428.

Windmills.

5. Drawings of windmills. (Scales 1 : 32 and 1 : 24.) Contributed by Hyde Clarke, Esq., 1866.

The sectional drawing, dated 1802, shows a four-armed windmill, driving two pairs of millstones, a dressing machine, and a sack-hoist. Beneath the mill is a nearly horizontal water-wheel, connected by bevel gear with the main shaft, and probably provided as an alternative source of power. The cap of the mill is carried on friction wheels, and is automatically slewed by a small wind-wheel whose plane is at right angles to that of the large arms.

The regulating arrangement of this mill was patented in 1789 by Stephen Hooper, of Margate, and forms an early instance of the application of the centrifugal governor. Each sail is made up of small elements wound on separate rollers, and when the velocity of the windmill increases, centrifugal action

causes these elements to be rolled up against the pull of a weighted spiral drum or fusee within the mill. Hooper also described a conical pendulum governor which was to feed more corn into the stones when the speed increased.

The sectional elevation, dated 1804, shows the construction of a four-armed windmill driving three vertical rolls, probably for squeezing the juice from sugar-cane. The cap of the mill is carried on friction wheels, and is turned by a large hand-wheel provided with a worm that gears into a spur ring secured to the top of the tower; by these means the mill can be adjusted as the direction of the wind alters. M.1010–1011.

6. Model of pumping windmill. (Scale 1 : 12.) Lent by Messrs. J. Warner & Sons, 1888.

In this windmill, patented by Mr. F. Warner in 1868, the vanes yield as the pressure of the wind increases, and thus automatically adjust themselves to suit its force.

The mill has 24 radial vanes, mounted between two rings, and each pivoted about its front edge so that the angle which it presents to the wind may vary. Levers on the ends of the pivots are connected with another ring which is attached to a rod, running through the centre of the axle, and connected with a balance weight which keeps adjusting the vanes to such an angle as to make the resultant pressure on them constant. A tail is provided for setting the wheel of vanes into the wind. The mill is mounted on a wooden tower and is arranged to drive a small pump from an eccentric on the axle. It is stopped by turning the vanes edgeways to the wind by means of a rod attached to the weighted lever. M.1951.

7. Model of pumping windmill. (Scale 1 . 12.) Lent by Messrs. T. McKenzie and Sons, 1888.

This form of self-regulating windmill was introduced by Mr. D. Halliday in 1877.

The vanes are arranged radially in six groups forming sectors of the complete disc. The sectors are pivoted at the middle on axes forming chords of a circle, and levers on them are connected with a sliding sleeve on the axle, which is in turn connected with a weighted lever normally holding the vanes parallel with the wind. The angle of the sectors is adjusted by means of a lever and a rope passing over a pulley and attached to the weighted lever. The mill is directed by a tail, and is mounted on a tower. In the model it drives a pump, at the ground level, from a crank on the axle, but the machine is also used for driving light machinery by gearing and shafting. M.1950.

Water-wheels.

8. Models of wooden water-wheels made at Freiberg, Saxony. (Scale 1 : 10.)

These show various types of timber water-wheels, together with details of the joints employed in their construction.

In the "current" wheel the radial blades dip into a running stream, and utilise only a small proportion of the energy of the water. The other three models are forms of overshot water-wheel; one has a closed sole plate, and so is unable to fill or empty its buckets rapidly through the lack of ventilation; the other two represent wheels with ventilated buckets. M.2753.

9. Model of water-wheel. Watt Collection, 1876.

This is an overshot wheel with the usual timber shaft, but on one side the wheel is provided with a toothed ring from which the power can be taken off at once at the highest speed, without transmission through the main gudgeon. The teeth are external to the rim; in later wheels internal teeth were adopted, and this constituted a still further improvement. M.1813.

10. Models of water-wheels for mine drainage. (Scales 1 : 12 and 1 : 24.) Received 1851.

The larger model shows a portion of a breast wheel erected at the Devon Great Consolidated Copper Mines near Tavistock, to work the pumps in three shafts: the wheel was driven by the River Tamar, and the power was transmitted to the pumps, which were nearly half a mile away, by means of iron rods 3·25 in. diam. carried on guide rollers. The excess weight of the spear rods in the shaft was partially balanced by bobs placed near the wheel so that the transmission rods were always in tension. The wheel was 40 ft. diam. by 12 ft. face, the oak axle was 5 ft. diam. with cast-iron journals 15 in. diam., and at each end had a crank giving a stroke of 42 or 48 in. as required. The wheel was of the high breast type, with the water laid on at 20 deg. from the summit, and its normal speed was 4 rev. per min. Each of its 112 buckets was formed of two deal boards secured to flanges on the cast-iron shroudings; the backing of the buckets, or the sole of the wheel, was also formed of deal boards.

The smaller model shows a similar arrangement adopted at the Wheal Friendship, also in Devonshire. The wheel was 50 ft. diam. by 10 ft. face, and had 180 buckets built of wrought iron; the axle was a hollow iron casting with flanged ends, but the arms were of wood. The power was transmitted to the mine pumps by wrought-iron rods, and balance bobs were used, but these were arranged in pits behind the wheel. M.1417–8.

11. Model of breast water-wheel. (Scale 1 : 12.) Lent by Messrs. Whitmore and Binyon, 1888.

In this type of wheel the water is laid on at about the level of the axis. The water acts by gravity, and the buckets are so shaped as to retain the water as long as possible during their descent. To ensure rapid filling and emptying, the buckets are ventilated, *i.e.*, a narrow space is left between each on the inner side or sole.

The construction of the wheel is wholly in iron; wrought iron buckets are bolted between two cast iron spiders with one or more intermediate cast iron supports, according to the width. The power is taken off by spur gearing, made in segments, bolted to the rim, and is not transmitted through the axle, as in older practice, thus permitting considerable reduction in weight. The sluice gate is controlled by rack and pinion and hand gear.

The efficiency of breast wheels is about 55 per cent. M.2254.

12. Model of Poncelet's water-wheel. (Scale 1 : 10.) Made by MM. Regnard Frères, 1891.

This shows the efficient form of undershot water-wheel introduced in 1824 by Gen. J. V. Poncelet; the chief features are the backwardly curved form of the floats, which are of iron, and the absence of a sole plate. The water is delivered to the wheel tangentially almost at the lowest point by means of an inclined sluice gate moved by hand-wheel, spur gear, and rack. The proportions are such that the water enters the buckets, without shock, with the velocity due to the head, and exerts pressure upon the curved floats as its direction of motion is being deflected; it also gives a reaction impulse when leaving the buckets under gravity. The water is discharged with but little remaining forward velocity so that a maximum efficiency of 65 per cent. is obtainable; the arrangement, however, becomes cumbersome when the fall exceeds 4 ft. M.2400.

Turbines.

13. Model of Pelton or "Hurdy-Gurdy" water-wheel (working). (Scale 1 : 4.) Lent by the Sandycroft Foundry and Engine Works Co., 1890.

This is a form of impulse turbine much used in mining districts and other situations in which considerable head is available, as its high speed and great power render it a most convenient motor, while its extreme simplicity minimises the risk of failure.

The early form of the machine consisted of a wheel having radial floats or paddles projecting from it, upon which a rapid stream of water was directed by a shoot; reversal or stoppage were both effected by moving the shoot—the supply of water in such cases generally far exceeding the power requirements. Wheels with concave vanes (as in the Italian amalgamating mill) were in use before the year 1737, and Poncelet in 1827 proved their superiority over those with flat vanes, but it was considerably later that in the mining districts of California the practical development of this important form of turbine was chiefly effected. The original "miner's wheels" there employed were shrouded and had vanes made as triangular prisms; they had an efficiency of about 40 per cent., but were subsequently improved by the adoption of cup-shaped vanes. In 1874, however, Mr. J. Moore improved these vanes by forming them with a central wedge-shaped ridge which split the jet, while in 1878 Mr. L. A. Pelton independently arrived at this double construction of cup, and to him the commercial introduction and development of the Pelton wheel is chiefly due.

The model has a central wheel of cast iron, to the rim of which are secured twenty-eight double buckets of gunmetal 2·3 in. wide, the over-all diameter of the revolving parts being 20 in. The shaft is carried in three bearings, near the central one of which a screen or partition would be fitted to prevent water splashing upon the belt pulley by which the power obtained is transmitted. The supply water, which is usually brought through light pipes of sheet steel is, after passing through a sluice valve, led by a conical pipe to a removable discharge nozzle, so that by changing the nozzle the load on the wheel may be greatly altered without seriously reducing the efficiency of the motor.

Each bucket or cup consists of two semi-cylindrical portions, uniting in a central ridge which divides the entering water jet, so that each half slides round the inside of its cup and has its motion reversed before escaping at the opposite edge; by running the wheel at a circumferential speed slightly less than half the velocity with which the water issues from the nozzle the water is discharged from the cups, dead, its energy being completely transferred to the wheel. To facilitate the escape of the dead water from the wheel, the buckets are given a forward inclination; the wheel must, however, in all cases, be above the level of the tail race; under suitable conditions an efficiency of over 80 per cent. is easily obtained with such a machine.

M.2352.

14. Encased Pelton wheel. Presented by P. Pitman, Esq., 1903.

This is a small example of an arrangement of impulse turbine in which, by enclosing the wheel, the machine is adapted for use as a motor within a building; the pressure water may be obtained from the domestic mains or other supply, while the used water is led away by a pipe from the bottom of the case.

The centre of the wheel is a cast iron disc to which are riveted twenty double-cupped buckets of bronze, which are given a backward slope to facilitate the discharge of the used water; the shaft of the wheel is carried in external bearings secured to the sides of the casing, and has a pulley attached by which the power given off is transmitted by a belt. One side of the casing is removable so as to facilitate examination of the wheel. The supply water is delivered as a horizontal jet near the bottom of the wheel, while somewhat higher up in the case in the opposite side is a fixed blade, just clearing the buckets so as to prevent used water from being carried round and thereby absorbing power by falling on the wheel. The speed is adjusted by a throughway sluice valve on the supply pipe, but to permit of economical working at much below the full power, two extra nozzles of less area than the standard one are provided and arranged for attachment by the removal of a box nut.

The wheel shown is intended to run at 1,300 rev. per min. with a supply pressure of 90 lb. per sq. in., when it gives off 0·25 h.p.; at a lower pressure the speed and power are less. Similar wheels have been worked at pressures of from 1 to 1,030 lb. per sq. in. M.3296.

15. Model of Pelton wheel. (Scale 1 : 5.) Made by Peter Koch, 1913. Plate IX., No. 2.

This represents a tangential impulse turbine or Pelton wheel, made by Messrs. Amme, Giesecke & Konegen of Brunswick, and embodying features patented by Messrs. V. Gelpke & P. Kugel in 1905 and 1911. Its speed is controlled, under varying load, by a servomotor nozzle regulator actuated by a centrifugal governor, while an automatic relief valve, which comes into action when the nozzles are closed rapidly, prevents a dangerous rise of pressure in the pipe line.

The turbine has a single disc wheel with 16 buckets bolted to its edge, the effective diameter being 24·6 in.; this is keyed on a shaft supported by ring-oiled bearings which are bolted to the sides of the casing enclosing the wheel. Two variable nozzles are mounted in the casing, at right angles to one another, and the supply pipe has a branch leading to each. Each nozzle consists of a cylindrical casing, to the inner end of which is fitted a sliding convergent tip. At the centre of the nozzle is fixed a spear-shaped rod or needle, the point of which projects through the tip, thus constituting an annular channel through which the water issues; the needle is so shaped that the water beyond its point forms a solid cylindrical jet. The buckets are ellipsoidal in shape, and are notched at the outer edge, so that they do not cut into the jet until they reach their effective position. The sliding nozzle tips are connected, by links, levers, and connecting-rods, with the main piston of the servomotor speed regulator; an oil pressure of 220 lb. per sq. in. acts on one side of this, and opposes the water pressure which acts on the nozzles and tends to keep them fully open. The movements of the servomotor piston are controlled by a piston valve which allows oil to enter or leave the cylinder; this valve is attached to a centrifugal governor, and it works inside a perforated sleeve connected with the piston, by a roller and incline. As the piston moves, the sleeve moves also and counteracts the movement of the governor valve, thus closing the oil passages, and causing the piston, and with it the nozzles, to take up a definite position corresponding with the position of the governor valve.

The pressure relief valve is fitted to the inlet pipe, and it consists of a sluice valve attached to a trunk piston fitted within an oil cylinder. At the centre of the piston is a long hollow rod which serves as a valve to distribute pressure oil to either end of the cylinder, the oil being led through the rod from an upper reservoir. The rod carries a piston fitting easily within another oil-filled cylinder, which is connected with the servomotor in such a manner that it is positively lifted when the nozzles are closed, but is not affected when they are opened. A sudden closing of the nozzles, and consequent lifting of the cylinder, will raise the central valve and thus open the relief valve, while the loose-fitting piston will afterwards allow the valve rod, which is weighted, to fall slowly, and thus cause the relief valve to close again. The servomotor is mounted on a large tank base which serves as an oil reservoir, and the pressure is obtained by means of a rotary pump driven by a belt from the turbine shaft; a hand-pump is provided for use when starting.

The turbine develops 194 h.p. at 600 rev. per min., using 424 cub. ft. of water per min., under a head of 302 ft. It has an efficiency of 80 per cent., which remains constant over a wide range of load. M.4169

16. Model of Fourneyron's turbine. (Scale 1 : 4.) Made by T. B. Jordan, Esq., 1842. Plate IX., No. 3.

This represents an outward flow turbine erected in 1837 at St. Blazien, Baden. It was constructed by Benoît Fourneyron in 1827, after he had spent four years in experimenting.

The machine consists of a vertical cylindrical chamber with a side inlet for the water, and a central pipe below through which the water passes to an annular outlet at the base of the pipe. This outlet is fitted with thirty guide blades which direct the water in a tangential course as it escapes. Surrounding this passage is a wheel, keyed to a vertical shaft, and provided with vanes

between which the water flows as it passes from the inner to the outer circumference, where it is finally discharged. A full-sized model of a wheel 2 ft. diam. is seen below.

The toe of the shaft is carried in a special bearing, having oil supplied under pressure, and the power given off by the shaft is transmitted by bevel gear at the upper end. The central pipe containing the guides is carried by three screwed rods connected above by gearing, by which the pipe can be accurately raised, so as to contract the supply passage into the wheel if less than full power is required. The water under pressure is discharged in a tangential direction from the fixed guides, and on passing between the vanes of the enclosing wheel has its direction of motion gradually changed until the energy of the water has been transferred to the wheel, when the water is discharged at the outer rim, dead. M.2748.

17. Fourneyron turbine. Received 1907.

This is a small outward-flow turbine of the Fourneyron type (*see* No. 16). It has a horizontal shaft, running in a long bearing at one end of the casing, carrying the turbine wheel at its inner end and a driving pulley at its outer end. The water enters at the top of the other end of the casing and passes horizontally through a gauze strainer to the guide blades, which are secured to the end of a central support, and thence outward through the surrounding wheel passages where its kinetic energy is absorbed. The dead water passes away through the bottom of the casing. The wheel has an inside diameter of 3 in. and a blade width of 0·22 in. M.3509.

18. Schiele turbines. Presented by the North Moor Foundry Co., 1863.

These are small examples of the mixed-flow type. The water, having a pressure due to the head, is introduced through a pipe to the spiral outer casing, through which it passes to a series of inclined inlets in an inner casing; passing in through these inlets in a spiral direction, it impinges upon the curved and inclined vanes of the revolving drum, splits into two currents, and passes out at the sides, giving rotation to the shaft. The double construction of the wheels avoids the heavy end-thrust that would otherwise result from the axial delivery of the used water. M.941.

19. Model of a vortex turbine. (Scale 1 : 6.) Lent by Messrs. G. Gilkes & Co., 1888.

This is a working model of an inward-flow turbine of the type patented in 1850 by Prof. James Thomson, the result of whose investigations of the laws of the free vortex have been applied in the design.

It consists of a large casing, into which the water enters and from which it escapes axially by two discharge pipes. Fixed in the casing are spiral blades or vanes, which give a spiral direction to the water as it approaches and impinges upon the curved vanes of the drum, to which it imparts rotation. The guide blades are capable of simultaneous adjustment from the outside of the casing, and in this way the supply orifices are reduced to suit the work to be done, and the efficiency of the machine maintained when working at partial loads.

This turbine would use 600 cub. ft. of water per min. with a fall of 25·5 ft., and would give about 22 h.p. at 75 per cent. efficiency; it would make about 250 rev. per min. If the model itself is worked with water it will make about 560 rev. per min., the passages through which the water finds its way to the wheel being properly proportioned for this speed. By having the delivery pipe ends under water the full power of the "suction head" is utilised, so that these machines can be placed more than 20 ft. above the level of the tail water without loss of energy. When, however, these turbines are intended to work drowned, they are usually arranged to work on a vertical axis.

Photographs and particulars of actual turbines are given. M.1919.

20. Vertical turbine. Lent by S. Howes, Ltd., 1899.

This small example of the "Little Giant" double turbine belongs to the mixed-flow construction so generally adopted in America. In the machine shown, moreover, the case and wheel are each divided by horizontal diaphragms, so that the upper and lower portions form complete machines; a vertical sluice at the entrance of the spiral supply chamber when half open only admits water to the lower section, thus maintaining the same efficiency on half as on full load.

The turbine is designed to work drowned, the level of the fall water being such that the wheel when running is just submerged, although a rise in the tail race does not interfere with the working, except in so far as the head is thereby diminished. The bottom step or "toe-bearing" consists of a lignum-vitæ pin working in an inverted cup formed in the lower end of the shaft, while the upper bearing is in three lignum-vitæ bushed pieces, separately adjustable.

The example is a turbine with double wheels 6 in. diam., and is intended to exert 10 h.p. at 1,063 rev. per min. with 152 cub. ft. of water under a head of 44 ft.; under other heads, energy proportional to the 3/2th power of the head is obtained, the efficiency being practically constant, but the quantity of water passed diminishing with a reduced head. For 1,000 h.p. on a 41 ft. fall the diameter of the turbine employed is 44 in., and it runs at 160 rev. per min.

This form of turbine is also made with its axis horizontal and enclosed in a case fitted with suction pipes, so that it can be arranged as much as 20 ft. above the level of the tail race. M.3047.

21. Diagram of the Niagara Falls power plant. Presented by the Institution of Civil Engineers, 1896.

The available energy of the Niagara Falls is about five million h.p., to generate which by the agency of steam would, it is estimated, require the consumption of the whole of the world's present output of coal. The hydro-electric schemes already in progress will utilise more than a tenth of this energy.

The diagram shows two of the turbines and their dynamos in the first portion of the scheme of one of the supply companies—The Niagara Falls Power Co.—which began work in 1890 and first delivered current in 1895. The water is conveyed by an intake canal 250 ft. wide, 1,700 ft. long, and 12 ft. deep, to the power house, where there is a wheel slot for the turbines 178 ft. deep and the same in length cut in the solid rock. A tail-race tunnel, 21 ft. high by 19 ft. wide, conveys the dead water to the river below the falls. The available fall is 136 ft. and the penstocks are 7·5 ft. diam. The turbines, 10 in number and each of 5,000 h.p., are of the twin outward flow type designed in Switzerland and made in the United States. A governor and a ratchet relay acting on a cylindrical sleeve on the outside of the wheel regulates the supply. The water pressure acts on the cover of the upper turbine, but is relieved from acting on the lower turbine, thus giving an upward pressure counterbalancing the weight of the shaft and the attachments amounting to about 70 tons. The dynamo is at the top of the shaft at the ground level. It is the two-phase alternating type running at 250 rev. per min., giving a voltage of 2,200 with a frequency of 25 periods per second.

(*See* Proc. Inst. Mech. Eng., 1906, p. 135.) M.2919.

22. Hydraulic turbine governor. Lent by Percy H. Pitman, Esq., 1915 and 1917.

This form of governor for hydraulic turbines was patented by Mr. Pitman in 1913. It is of the compensated relay type in which a centrifugal governor, driven by the turbine, moves a relay valve that controls the supply of pressure water or oil to a servomotor cylinder, the piston of which operates the turbine gates or nozzles.

The motor cylinder is mounted horizontally on a baseplate and has a guided crosshead which is connected with the gate or nozzle to be moved. To the top of the cylinder is bolted a pillar carrying a Hartung governor (*see* No. 312), which is driven by skew gearing and a silent chain, while the relay valve casing is fitted on one side of the pillar. On the sliding sleeve of the governor an aluminium crosshead is mounted and is prevented from rotating by stops; the relay piston-valve is attached to one end of the crosshead and the plunger of an oil brake to the other end, no floating levers being employed. A perforated sleeve surrounds the piston valve, and its lower end is connected with an eccentric fixed on a shaft that is partially rotated by the movement of the motor piston. Ports are formed in the valve casing and sleeve, by means of which the pressure fluid is distributed to either end of the servomotor cylinder. When the speed increases, the governor lifts the piston valve and admits pressure to one end of the motor cylinder, while the other end is opened to the exhaust. The motion of the piston then raises the compensating sleeve which closes the ports; the piston is thus caused to take up a definite position corresponding with the position of the governor valve, and hunting is prevented. The valve sleeve is coupled by rolling levers with the oil brake cylinder, which is fitted with a check valve so adjusted that, however sudden the change of load, the action of the governor is not interfered with by the back action of the sleeve. The governor is fitted with ball bearings throughout, and is constructed so that all parts are accessible. For starting, the pressure fluid can be admitted directly to the motor cylinder by means of a four-way cock fitted to the supply pipes.

The governor may be worked with either water or oil at a pressure of about 150 lb. per sq. in.; when using oil it is usually mounted on a self-contained tank bed fitted with the pressure pumps, etc. (*see* No. 15). An adjacent sectional drawing shows the internal construction of the governor.

Inv. 1915–125 and 1917–24.

Air and Water Pressure Motors.

23. Compressed air motor. Lent by the International Pneumatic Tool Co., Ltd., 1901.

This is a small portable machine for rotating the tools used in drilling, tapping, tube expanding, etc., by the application of mechanical power, so as to reduce the time otherwise necessary in performing such work by hand labour alone.

The sectioned example shown is a piston motor, patented in 1896 by Mr. H. J. Kimmans, in which there are four fixed single-acting cylinders arranged in pairs in two planes at right angles, and driving a two-throw crankshaft having cranks at 180 deg. Two pistons are connected with each crankpin, so that a fairly uniform turning effort shall be maintained. To reduce the bulk of the machine, the connecting-rod ends are in the form of hinged clips embracing their crankpin, one being forked and bearing outside the other; the ends also embrace the rods, to which they are secured by screwed sleeves. Each pair of cylinders is provided with a hollow piston valve, sliding in a bush and driven by an eccentric; the valve admits air to each cylinder alternately, through suitable ports in the casing and bush, which are so proportioned as to give expansive working; the exhaust takes place along the axis of the valve.

The cylinders and crankshaft are enclosed in a casing which forms an air chamber, and is provided with a cover through which passes a screwed sleeve, with a star handle, for feeding the drill. The tool holder runs on a ball thrust bearing, and has a conical socket for drills and an externally screwed boss; it is driven from the crankshaft by spur gearing which reduces the speed in the ratio of 1 : 7.

The cylinders are 2 in. diam., 2 in. stroke, and the brake h.p. exerted is 1·5, with a consumption of 35 cub. ft. of free air per min. The air pressure used is from 70 to 100 lb. per sq. in., and the maximum duty of the machine is to drill, in metal, holes of 2 in. diam. The weight of the motor complete is 35 lb.

M.3208.

24. Organ blower (working). Received 1897.

This is a water-pressure engine designed for working the bellows supplying air to an organ, but the cylinder in its action resembles the steam cylinder of a direct-acting steam pump. The supply of water is controlled by a valve connected with the air reservoir, so that the speed of working is automatically adjusted to the consumption of wind.

The blower shown has a cylinder 5·5 in. diam. by 10 in. stroke, and is fitted with a valve gear patented by Mr. D. Joy in 1874. The piston-rod is directly attached to the bellows, but has on it a tappet which reverses the distributing slide valve on the completion of each stroke. This slide valve is of the piston type, but is in reality two valves combined in one, for by its sliding motion the valve acts as the main slide valve, while by a rotary motion through 20 deg. it acts as a plug valve which does duty as the auxiliary valve. The plug is in the middle of the length of the piston slide, and by its motion lets the water to and from the ends of the chest of the piston valve, so causing the sliding motion of this valve. The rotation of the valve is performed by two inclined horns, secured to the valve-rod and moved by the tappet on the piston-rod. A simple tappet moving a single slide valve will not work at a slow speed without assistance, and it is for this reason that some form of auxiliary valve is almost invariably introduced. A sectional drawing further illustrates the construction. M.2971.

25. Water motor with oscillating cylinder (working). Lent by Messrs. W. H. Bailey & Co., 1894.

This is a small example of Haag's high-pressure water motor, for pressures up to 300 lb. per sq. in. These motors are frequently used in mine workings, the water for driving being obtained from the delivery pipe of the main pumping engine, and the motor discharging its exhaust water into the mine sump.

The cylinder of the engine oscillates on two hollow trunnions, closed at the outer ends, the hollow spaces within each trunnion being divided into two compartments, one of which on each side communicates with either end of the cylinder. Two slots cut longitudinally in the trunnion serve for ports for admission and exhaust of the water, one slot giving admission to each end of the cylinder. In the lower part of each bearing there are three ports, a wide one in the middle leading to the exhaust pipe, and a narrower one on each side of this communicating with the supply pipe. The oscillation of the cylinder causes the ports in the trunnions to slide over those in the bearings, so opening up each end of the cylinder to exhaust or pressure alternately, just as in the case of an ordinary slide valve. The supply and exhaust pipes are each fitted with an air vessel to prevent shocks in the pipes.

This motor has a cylinder 2·5 in. diam. by 4 in. stroke, and when making 100 rev. per min. under a pressure of 150 lb. gives off 1 brake h.p. Larger sizes are made up to those having 9 in. cylinders, which, running at 50 rev. per min., exert 24 brake h.p. under 150 lb. pressure. M.2566

26. Water-pressure motor (working). Lent by the Glenfield Co., 1896.

This is an example of Wilson's water motor for pressures up to 200 lb. per sq. in.; such motors are intended for driving small quick-running machinery, dental drills, ventilator fans, etc.

The two cylinders are double-acting, fixed with their axes at right angles to each other and working by connecting rods a crankpin common to both. One eccentric actuates both valves which are of the solid piston type. To prevent shock at the reversal points a small conical-seated relief valve is fitted to each water passage opening into the valve chamber, the pressure there keeping them closed under normal conditions. The supply and exhaust passages are cast with the framing connecting the two cylinders.

This motor has cylinders 1·25 in. diam. by 1·5 in. stroke, and when running at 200 rev. per min. under a pressure of 150 lb. exerts about 0·3 brake h.p. M.2965.

27. Hydraulic motor, in section. Made by the Hydraulic Engineering Co., 1888.

This is a small motor on Brotherhood's system with three single-acting cylinders inclined at 120 deg. to one another, and having trunk pistons with cup-leather packing. The connecting rods are always under compression and are ball-jointed at the piston end, while at the other extremity they each embrace 90 deg. of the crankpin. The water is distributed by a rotating disc valve (shown separately in section) which has an opening from the outside for pressure, while the exhaust passes through the spindle; the port face is of lignum vitæ.

The example has cylinders 1·75 in. diam. by 2·5 in. stroke. It gives 2 brake h.p. at 105 rev. with 7 gal. of water per min. at 750 lb. pressure, or 2·5 brake h.p. at 87 rev. with 5·75 gal. at 1,050 lb. pressure. K.497.

28. Hydraulic engine. Lent by the Glenfield Co., 1896.

This is a small example of a three-cylinder water-pressure engine, suitable for pressures up to 1,000 lb. per sq. in.

The three cylinders are cast together, their axes radiating at 120 deg. to one another, and they are always open at their inner ends to the crank chamber. The pistons are packed with cupped leathers and are hollowed out to receive the spherical ends of the thrust bars by which motion is given to the crank. The pressure is always on the outer end of the piston, so that the thrust bars are in compression and take up their own wear. The water is admitted and exhausted by means of a circular disc valve driven by a stem from the crank-pin and working on a face which in the case of the larger engines is made of lignum vitæ. Water is admitted at the side of the valve chamber and exhausts by the centre of the valve.

This example has cylinders 1 in. diam. by 1·5 in. stroke, and when running at 250 rev. per min. with 600 lb. pressure gives off about 0·75 brake h.p. M.2965.

29. Hydraulic swash-plate engine (working). Lent by Messrs. Sir W. G. Armstrong, Whitworth & Co., Ltd., 1910.

This is a type of engine in which a shaft, having an oblique disc or swash-plate fixed to it, is caused to rotate by the successive pressures upon the disc of a number of pistons, working in cylinders arranged in a circle, with their axes parallel with the shaft. Such an engine may have a large number of cylinders compactly arranged and gives a very uniform torque.

The small example shown has 16 cylinders bored horizontally in a single casting; the pistons are packed with cup leathers and bear against the rounded ends of the piston-rods. The outer ends of the rods are ball-shaped and are held in a circular ring which bears against the swash-plate, ball bearings being interposed to reduce the friction, The ring is controlled by two diametrically opposite pins which slide in horizontal slots attached to the bed-plate of the engine. The end thrust is taken by a row of balls placed between the back of the swash-plate and a fixed disc which is surrounded by an outer casing formed in one with the driving shaft.

The valve gear is of the simplified form patented by Mr. F. G. D. Johnston and Sir W. G. Armstrong, Whitworth & Co. in 1908. A single rotary valve is used, placed behind the cylinder and having five inlet and five exhaust ports disposed in a circle; the valve seat has 16 cylinder ports symmetrically arranged and these are connected with the cylinders in a particular order. This arrangement besides reducing the number of ports in the valve, and therefore its size, also requires that the valve shall rotate at only one-fifth of the speed of the main shaft, this reduction being effected by means of epicyclic gearing. The valve opens and closes the cylinder ports at the ends of the stroke, and eight cylinders are working while the remainder are exhausting. The engine may be reversed by interchanging the inlet and exhaust pipes.

The cylinders are 0·75 in. diam. and the water pressure is 1,000 lb. per sq. in. A full-size sectional drawing is also shown. M.3796.

30. Tidal motor. Contributed by Richard Roberts, Esq., 1858.

This apparatus, patented by Mr. Roberts in 1848, is shown arranged for clock-winding, or doing lighthouse work, by tidal energy.

The machine is erected over a tank or well to which the tide has access; into this hangs a weight and also a float, connected by a chain that passes over a sprocket wheel on the overhead shaft, then round a loose wheel on the framing and back over another sprocket wheel. These wheels are connected with the shaft by ratchet and pawl mechanism, which causes both upward and downward movements of the float chain to rotate the shaft, always in one direction. The power so obtained will cease for a while during the turn of the tide, and therefore, when continuous motion is required, an additional mechanism is added. On the end of the intermittently rotated shaft is a sprocket wheel, and on the shaft to be continuously rotated, which is in line with it, is another sprocket wheel; over the two wheels hangs an endless chain, in the loops of which are two weighted sheaves, one of which is much the heavier, the difference being the driving weight. When the tidal motion is rapid the excess power is stored by lifting the weight, while, when the tidal movement stops, this weight gives off its stored energy in descending, and so keeps the driving shaft in motion. The weighted sheaves are connected by a hanging chain which prevents the inequalities in the effort which would otherwise arise from the varying length of chain on the driving side. Inv. 1858–9.

STATIONARY STEAM ENGINES.

The earliest known record of the employment of steam as a motive agent is that of Hero of Alexandria, a philosophical writer who flourished, it is now believed, about 50 A.D. He left several treatises on mechanical subjects which are interesting as records of the knowledge of his time; of these, the best known is his compilation on "Pneumatics," in which he describes the *œolipile*, or reaction steam engine, and a steam jet supporting a light ball (*see* No. 31); the first of these is said to have been used practically during succeeding centuries, but was never more than a toy owing to its inefficiency. A few proposals for using high pressure steam that bore fruit much later are met with in philosophical writings up to the middle of the seventeenth century (*see* Nos. 32 and 33).

It was at this time, however, that the important discovery was made that the atmosphere was a fluid possessed of weight, the pressure due to which could be excluded at will from the interior of a closed vessel so as to obtain a vacuum (*see* No. 34), facts destined to have a most important bearing on the development of the steam engine. The means for obtaining this vacuum were found in the adaptation for the purpose of the common syringe or the bucket pump. The properties of the air pump and the experiments that could be made with it became widely known, but it was some years before it was realised that the converse was also true, *i.e.*, that if a vacuum could be obtained readily below the bucket or piston, then the pressure of the atmosphere could be utilised for doing mechanical work. Acting on this idea, Huygens in 1678–9 exploded a charge of gunpowder in the bottom of a vertical cylinder. The greater part of the air and of the gaseous products were expelled through non-return valves; the cooling of the remaining gases produced a partial vacuum below a piston which then descending owing to atmospheric pressure, doing work by means of a cord over a pulley. Papin, in 1690, demonstrated the suitability of steam for producing the vacuum (*see* No. 36), but was no nearer solving the problem of how to repeat at frequent intervals this reciprocating motion by causing differences in pressure behind the piston.

In the meantime the idea of raising water by the direct pressure of steam upon its surface in a closed vessel had received attention. The introduction of an apparatus combining not only this principle but also that of the reduction of pressure resulting from the condensation of steam in the same vessel, together with valves and cocks which enabled the operations to be repeated indefinitely, was embodied in a remarkable manner in a practical machine for raising water, patented and constructed in 1698 by Thomas Savery (b. 1650, d. 1715) and known as the "fire engine" (*see* No. 37). Whether Savery was indebted in any way to the labours of the Marquis of Worcester (*see* No. 35) and others, we do not know, but it may safely be said that he was the first to utilise fuel as a practical means of performing mechanical work. Already there existed a great sphere for the employment of such an engine in the drainage of mines; Savery appears to have erected several engines for this purpose, but their range was limited by the materials and methods of boiler

construction then known, to a maximum lift of about 80 ft.; hence a mine of even moderate depth would require a number of engines at intervals, one delivering into the sump of another. This drawback, and the danger of explosion owing to the lack of a safety valve, greatly restricted the employment of the engine, so that it was in positions demanding only a single lift (*see* No. 38) that we find it to have been used.

Meanwhile, after many years' work Thomas Newcomen (b. 1663, d. 1729), assisted by John Cawley (d. 1717), both of Dartmouth, who had been following in Papin's steps, had succeeded prior to 1712 in perfecting the atmospheric engine, from which the growth of the modern steam engine can be clearly and continuously traced. However much Newcomen was indebted to the work of his predecessors, the atmospheric engine must be regarded as so much in advance of anything which had gone before as to be practically a new invention. Newcomen adopted a separate vessel in which to generate the steam; furthermore, he hit upon the idea of injecting cold water into the cylinder in order to effect a speedy vacuum under the piston, but had, in consequence, to overcome the further difficulties caused by the condensed water and the air carried in along with the steam and water; lastly, to enable the machine to regulate and repeat its movements automatically, Newcomen provided valve gear. The engine thus equipped was applied to work a lifting or bucket pump by means of a lever or wooden beam (*see* No. 41). This and the vertical position of the cylinder necessitated by the water packing were features that survived for many years after the conditions that rendered them necessary had ceased to exist. As Savery's patent was sufficiently general to cover Newcomen's invention, although quite different in principle, and as it had been extended for twenty-one years, *i.e.*, till 1733, the inventors appear to have come to an understanding, for we find that the invention of the latter was exploited under the patent of the former.

It is scarcely possible to over-estimate the importance of the Newcomen engine, which in practically its original condition remained for upwards of sixty years the only economical and powerful agent for draining mines. So rapid was its adoption that Smeaton found that down to 1769 nearly 100 engines had been built in the Northern colliery districts and about half that number in Cornwall.

In 1763–4 James Watt (b. 1736, d. 1819), while engaged in repairing a working model of Newcomen's engine, found the consumption of steam to be much greater than he had imagined, and was thus led to make experiments and careful measurements of the temperature, pressure, and volume of steam, and also of the quantity of water required for its condensation. By these investigations he discovered that the chief waste in the engine arose from the cooling of the cylinder and piston surfaces by the water-spray used to condense the steam; this led in 1765 to his brilliant invention of the separate condenser, an improvement which at once halved the fuel consumption of the engine. The use of a snifting valve being impracticable, Watt devised

the air pump to clear out both air and water from the condenser. He then covered in the top of the cylinder to exclude the cooling action of the air and exposed it to steam from the boiler. He thus produced the single-acting beam pumping engine, a machine which is employed yet with economical results for raising water (*see* No. 615). These improvements were secured to Watt by patent in 1769, which was extended in 1775 for a period of twenty-five years at the time when he entered into partnership for a like period with Matthew Boulton.

The next step was to employ the engine for obtaining rotatory motion, and Watt, with several others, proposed to use the oscillating motion of the beam to drive a flywheel shaft by the intervention of a crank and connecting-rod. Watt, however, was forestalled in this application by a patent taken out in 1780, so he was obliged to resort to other means, and in his specification of 1781 described several arrangements for obtaining rotatory motion from a rocking beam including the "sun and planet" gear, with which all his mill engines were fitted till the crank patent expired. To obtain regular reciprocation from the single-acting engines, a weight equivalent to half the load of the piston was at first fixed on the connecting-rod or at its end of the beam (*see* No. 73), but it soon became evident that by making the cylinder double-acting, not only was the power of the engine doubled, but greater regularity in its speed was obtainable. This change, however, prohibited the use of the hitherto flexible connection, by chain and arch head, between the piston-rod and its end of the engine beam, but the difficulty was completely surmounted by Watt's introduction of the parallel motion bearing his name, which he stated to have been of all his inventions the one with which he was most proud. These improvements were patented in 1782 & 1784, and the first engine embodying them was made in 1784. From this time onwards the engine ceased to be exclusively an apparatus for raising water, and entered the much wider field of industrial employment.

The reduction in steam consumption resulting from cutting off the supply early in the stroke, and allowing the completion of the stroke to be performed by the steam while expanding, was discovered by Watt in 1769, and practically carried out at Soho in 1776, but he did not patent the invention till 1782.

The great success which attended the introduction of Boulton and Watt's engines stimulated other inventors (*see* No. 100). Among these was Jonathan Hornblower, who in 1781 patented and introduced the compound single-acting engine for pumping; the high-pressure cylinder was placed between the low-pressure cylinder and the beam centre. With the low boiler pressure in use at the period it proved less economical than the simple engine, and, as it embodied the separate condenser, was an infringement of Watt's patent.

To the last Watt was satisfied with having perfected the steam engine in its original form of a vacuum apparatus. Although he had experimented with high-pressure steam as early as 1761–2, and had included its use in his patent of 1769, he consistently opposed its introduction and restricted himself

to pressures of not more than 1 or 2 lb. above the atmosphere, owing to the risk of explosion with boilers as then constructed. Immediately after 1800, the date of expiration of his patent, an advance began which is still continuing at the present day. The vacuum has become of relatively less importance, and in the case of the high-pressure engine is dispensed with altogether. One of the first to advocate and introduce the latter was Richard Trevithick (b. 1771, d. 1833), who patented in 1802 a semi-portable engine of this type (*see* No. 109); his application of it to the locomotive engine (*see* p. 87) was, however, its most important development.

About 1800 also commenced the introduction of self-contained engines of low power, which should be more compact than the established beam type (*see* No. 103); this has gradually led up to the direct acting engine, which, although adopted in 1801 by Symington in the horizontal form, was slow in attaining recognition, but has now superseded the indirect type.

In 1804 Arthur Woolf (b. 1766, d. 1837) reintroduced the compound engine, and by expanding the steam from six to nine times was able to demonstrate its superiority in economy over the simple engine, owing to the reduction of temperature range and consequent losses in each cylinder; with increased pressures and temperatures the principle has been extended since with great advantage to engines in which the steam is used successively in three, four, or even five cylinders.

The demand which arose about 1880 for engines for driving dynamo-electric machinery resulted not only in the improvement of the existing type of slow-running engines (*see* No. 130) but also in the development of a new type of high-speed or quick revolution engines for direct driving (*see* No. 131), necessitating attention to such problems as balancing rotating, and reciprocating parts, the use of better constructional materials to keep down weight, closer governing, and forced lubrication. With this advance and with researches into the thermodynamics of the steam engine, Peter William Willans (b. 1851, d. 1892) is closely associated.

The economy resulting from the use of superheated steam by diminishing cylinder condensation losses was known early in the 19th century, but is now carried to greater temperatures than formerly, *e.g.*, Schmidt has employed 150 deg. C. of superheat. The difficulties of lubrication have been got over by the use of mineral oil and of packing by the use of soft metals for pistons and glands.

The advantages of obtaining rotatory motion from steam without the intervention of reciprocating parts are so great that ever since the time of Watt (*see* No. 133) much attention has been paid to the subject, resulting in the discovery of many new mechanisms. Within a chamber enclosing the shaft to be driven some abutment on which an unbalanced pressure can be exerted will usually be found; in many rotatory engines, however, reiprocating motion will be found to exist also. The excessive weight for the power developed has confined these engines, where successful, to low powers only.

The steam turbine, which has been developed practically within the last three decades, is also a rotary engine and shares its advantages, but differs both from it and the reciprocating type in that the working fluid acts, not by pressure, but by change of momentum. The simplest form, analogous to the impulse water wheel, consisting of a jet of steam acting on the vanes of a wheel, is very old (*see* No. 33) but inefficient. With a plain orifice there is considerable loss in converting the heat energy of the steam into kinetic energy. By using a diverging nozzle, Dr. C. G. P. de Laval (b. 1845, d. 1913) in 1889 was able practically to eliminate this loss. To obtain efficiency the vanes should travel at about half the speed of the fluid of the jet, and as this velocity is very great (*e.g.*, a difference of pressure of 200 lb. per sq. in. gives a velocity of 4,000 ft. per sec.), special arrangements and reduction by gearing to obtain practical shaft speeds were necessitated (*see* No. 144). To avoid exceeding these ordinary limits of speed, the Hon. Sir Charles A. Parsons in 1884 arranged side by side on the shaft a number of axial or parallel flow turbines in each of which a part of the pressure energy of the steam was converted efficiently into kinetic energy, the velocity resulting at each step being within desired limits (*see* No. 143). The condensing type introduced in 1891 demonstrated that the turbine could equal in efficiency and even surpass at high powers the reciprocating engine. The success of the Parsons turbine has resulted in the design of other successful types in which the number of wheels has been reduced without necessitating excessive shaft speeds. The chief of these are the Curtis and Rateau turbines (*see* Nos. 146 and 147), while a combined type, in which the earlier stages of a Parsons turbine are replaced by a Curtis wheel, is much favoured (*see* Nos. 149 and 152). Most steam turbines are of the axial flow type, but a few are of the tangential or radial flow types (*see* No. 154). The size of turbines has increased rapidly, some recent machines being capable of developing over 30,000 shaft h.p. The steam consumption of such machines is about 8·5 lb. per h.p. per hour.

31. Drawing of apparatus described by Hero. Æolipile (working), made in the Museum, 1914.

Hero of Alexandria, a philosopher who flourished probably about A.D. 50, in his treatise on "Pneumatics" describes a light ball, supported by a jet of high pressure steam issuing from a pipe terminating in a cup, and supplied from a cauldron.

He also describes the æolipile, which consists of a hollow ball mounted on its axis between two pivots, one of which, being hollow, serves as a steam pipe from a cauldron below, supporting the whole. The ball is provided with two bent nozzles, in a plane at right angles to the line joining the pivots. The reaction or unbalanced pressure due to the escape of the jets of high pressure steam tangentially to the ball, causes it to revolve on its axis.

M.2557 & Inv. 1914–398.

32. Drawing of apparatus proposed by Solomon de Caus.

This French engineer and architect proposed and published in 1615 an application of steam as a means of elevating water.

His scheme required a spherical copper boiler with an internal pipe reaching nearly to the bottom, and with a cock for filling it. The boiler was to be placed on a fire until the steam pressure forced the boiling water through the vertical pipe, to a height proportionate to this pressure. In an alternative scheme he proposed using the heat of the sun's rays to increase the pressure of a confined volume of air, and thus force up some of the water upon which it pressed. M.2557.

33. Drawing of machine designed by Giovanni Branca.

Branca was an Italian engineer who, in 1629, published a work in which he suggested a form of steam turbine. A powerful horizontal jet of steam was to be directed against vanes on the circumference of a fan wheel with a vertical axis, thus causing the wheel to revolve. Several applications of the resulting motion were described, but that shown in the drawing consists in the use of a reducing train of spur gearing by which pestles or gravitation stamps are lifted.

The apparatus is now manufactured as a child's toy; with an important alteration in the form of the jet and in that of the vanes it would, however, have resembled the efficient steam turbine of Dr. de Laval (*see* No. 144), provided the requisite high speed could have been maintained. M.2557.

34. Drawing of apparatus of Torricelli and von Guericke.

Evangelista Torricelli, an Italian physicist and a pupil of Galileo, in 1643 confirmed his instructor's speculations that the atmosphere had weight by measuring it with his invention of what is now known as the mercurial barometer.

Otto von Guericke, burgomaster of Magdeburg, directed his attention to the means of obtaining a vacuum and adapted the syringe for this purpose; in 1654 he showed his apparatus publicly. In the treatise he published in 1672, he described a number of experiments on the subject, including the one shown in the drawing in which a cylinder is fitted with a tight piston connected by a cord and overhead pulley to a weight; when the air under the piston was exhausted by an air-pump the weight was lifted. M.2557.

N.B.—Reproductions of Guericke's apparatus are to be found in the Physics Collection.

35. Drawing of contrivance described by the Marquis of Worcester.

Edward Somerset, second Marquis of Worcester, in his "Century of Inventions," which was written in 1655, although not published till 1663, included descriptions of "An admirable and most forcible way to drive up water by fire" and of a "water work"; in 1663 the benefits of a "water commanding engine" were secured to the Marquis for ninety-nine years by Act of Parliament.

In 1663 and 1669 eye-witnesses saw one of these engines, which had been erected by the Marquis at Vauxhall, raise water to a height of 40 ft.; this drawing is a speculative attempt to represent that engine. It shows a high pressure boiler, and two vessels into which the water to be pumped was forced by atmospheric pressure after the contained steam had condensed; this water was afterwards discharged by steam pressure on the system subsequently extensively practised by Savery. M.2557.

36. Drawing of apparatus proposed by Papin.

Denis Papin, in 1690, published a proposal for obtaining power by the action of steam. The apparatus was to consist of a thin, open-topped metal cylinder, fitted with a piston provided with a rod on which was a latch. A

small quantity of water was to be placed in the cylinder, and be heated by an external fire till the steam generated forced the piston to rise to the top, where it was to be retained by the latch. The fire was then to be removed, so that the steam should condense, thus causing the piston when released to move towards the bottom of the cylinder with such force as to enable it, by the aid of a rope and overhead pulley, to lift a weight. Papin stated that a cylinder 2·5 in. diam. would, if thus worked, raise a weight of 60 lb. once a minute through a height equal to the stroke ; this is equal to obtaining an unbalanced pressure of 12 lb. per sq. in.

In this proposal there is some suggestion of the principle of Newcomen's engine, but the unavoidable air leakage is not provided for; in 1707, moreover, Papin had abandoned it, and was working on an engine almost identical with that of Savery, the piston used being merely a loose wooden float to reduce the steam consumption arising from the direct contact of steam with the water to be lifted. M.2557.

37. Drawing of Savery's pumping engine.

In 1698 Thomas Savery patented an apparatus "for raising of water and occasioning motion to all sort of mill works, by the impellent force of fire." No drawing of the arrangement was deposited, but in the following year a model of the machine was shown at the Royal Society, and is illustrated in their Philosophical Transactions.

The apparatus in its simplest form consisted of a high pressure boiler supplying steam to a receiver, which was provided with suction and delivery pipes and the corresponding valves. By means of a regulator valve worked by hand, steam from the boiler was admitted into a receiver and allowed to blow through it till the air had been expelled; then the supply of steam was cut off and cold water from a cistern above was turned on to the receiver which, acting as a surface condenser, condensed the steam, so forming a partial vacuum into which the water rose from the suction pipe, the delivery orifice being at the same time sealed by its valve; the entering water further assisted in this condensation. Steam was then again admitted, and by its pressure forced the water in the receiver out through the delivery valve and pipe, the suction pipe in the meantime being closed by its non-return valve. M.2557.

See Phil. Trans. XXI. 1699, p. 228.

38. Engraving of Savery's single pumping engine. Presented by R. B. Prosser, Esq., 1900.

This shows an engine of the single receiver type (*see* No. 37) erected by Savery in 1712 at Campden House, Kensington. It is stated that the suction pipe was 16 ft. long but that it could be made to draw water about 28 ft.; that the steam pipe was 0·5 in. diam. and the suction pipes 3 in. diam.; that the receiver held 13 gallons of water; and that the height from engine to cistern was 42 ft. As the receiver was emptied four times per minute, the useful capacity of this engine was nearly 1 h.p. M.3113.

39. Drawing of Savery's improved pumping engine.

This arrangement is shown in Savery's treatise, "The Miners' Friend," published in 1702 in order to bring his engine into public notice as a means of draining mines. It shows two receivers acting alternately, but supplied from one steam boiler; there is also a smaller boiler for supplying the feed water to the main one, but there appears to have been no safety valve on either boiler. The vessels are of hammered copper, while the valve boxes and regulator are of brass and the pipes of wood. Steam was admitted alternately into the two receivers by a single regulator.

The coal consumption, as determined by Smeaton in an engine built in 1774, was 30 lb. per h.p. hour in water pumped, the "duty" being about 7·3 millions of foot-pounds per 112 lb. of coal burnt.

In a greatly improved form, with modern additions and workmanship, Savery's engine has been re-introduced, and is well known as the "pulsometer" steam pump (*see* No. 683). M.2557.

40. Drawing of the "fire mill" proposed by Amontons.

This design was submitted to the French Academy of Sciences in 1699 by Guillaume Amontons, but it suggests a hot-air engine rather than one working by steam. It shows a closed cylindrical copper drum, 31·8 ft. diam. by 12·8 ft. wide, divided into twelve compartments by radial partitions, and containing a smaller concentric wooden drum similarly divided. The partitions of the inner drum are fitted with flap valves and are partially filled with water, while a curved copper pipe leads from each of its chambers to a corresponding chamber of the outer wheel. The drum is mounted on a horizontal axle, and on one side is a furnace to heat the air in the chamber nearest to it, so that the resulting increased pressure and volume being transmitted to the lower cell of the inner or water drum will force the water through the clack into the next higher chamber, and so on, thus continually keeping the water at a higher level on one side of this virtual water wheel than it is on the other, and thereby causing the drum to revolve. After the heated air had done its work it was to be cooled by the water in which the lower part of the drum was immersed. Amontons estimated that the above apparatus was to be equivalent to no less than thirty-nine horses, but his determination of the working capability of a horse was about 14,000 foot-pounds per minute; this he considered was equal to the effort of six men. M.2557.

41. Drawing of Newcomen's pumping engine.

About the year 1712 Thomas Newcomen, of Dartmouth, assisted by John Cawley or Calley, introduced this machine, known as the "atmospheric" engine, in which were first embodied on a practical scale several of the leading features of the reciprocating steam engine. The engine was exploited under the patent granted to Savery, and, at the time, much confusion existed regarding the two inventions. Newcomen, however, by the introduction of the piston, was enabled to force water to any height, without using steam of higher than atmospheric pressure.

Newcomen's pumping engine consisted of a vertical open-topped cylinder fitted with a piston which, by chains, was connected with one end of a beam; the other end of the beam was similarly connected with the vertical rods of a pump, which might be at any requisite depth and of a size suited to the lift to be performed. The centre of the beam was fitted with trunnions, so that it could oscillate, and its ends were provided with arch heads in order that the chains resting on them should remain vertical while the beam worked. The cylinder was placed on the top of the boiler, so that when a valve was opened steam could enter the cylinder and allow the piston, which was being pulled up by the weight of the pump-rods at the other end of the beam, to rise. When the piston had reached the top of the cylinder the steam was shut off, and cold water from an overhead cistern was admitted in a jet at the bottom of the cylinder, thus condensing the steam and leaving a partial vacuum, so that the piston was forced downwards by the pressure of the atmosphere; when this down or working stroke was completed, the injection water was cut off. Steam was then again admitted for the next up stroke, during which the hot water at the bottom of the cylinder was being discharged through an eduction pipe terminating in a non-return valve while air that had come in with the steam and injection water was blown out through a "snifting" valve, so called from the noise it made; both these were seated in cisterns filled with water.

Ingress of air, which would have been fatal to the action of the engine, was prevented by keeping the top of the piston flooded with water; that which leaked past the piston was delivered with the water used for condensation, during the up stroke. Soft packing was used on the piston, as cylinders

could not at that time be bored; they were made of brass cast as thin as possible to reduce the heating and cooling losses.

The steam and injection valves of the engine were at first worked by hand, and it was often the most convenient way; one was so worked till recently, but it was very early in its history that these motions were given by a float in the boiler or by mechanism connected with the oscillating beam (*see* No. 42). M.2557.

42. Engraving of Newcomen's engine near Dudley Castle. Received 1912.

This engraving, of which very few copies are known to exist, shows the steam engine erected in 1712 by Thomas Newcomen in Staffordshire, near Dudley Castle. There is evidence pointing to the belief that it was the first one constructed by him. Thomas Savery appears as joint inventor, because it was under his patent of 1698 (*see* No. 37) that Newcomen's engine was exploited, although it was a totally different apparatus from that of Savery. The print is the earliest known document establishing the invention of the atmospheric engine, and is of great interest as showing that, at the date of publication in 1719, automatic valve gear had been evolved; indeed there is nothing to suggest that it was not in existence in 1712. The names of Henry Beighton and Humphrey Potter have been associated with this improvement.

A table of numbered references in letterpress at the sides of the print gives interesting particulars of the several parts of the plant.

The principle of action of the Newcomen engine will be understood from the preceding description (No. 41). The means whereby the engine was enabled to become self-acting was a new invention of far-reaching importance. This was the valve gear which was worked by a sliding beam or plug rod attached by chains to a smaller arch-head on the beam, and extended below to work a plunger pump for filling the cistern, whence injection and other water supplies were drawn. This plug rod actuated the regulator or steam valve, which was simply a sector-shaped plate, at the end of each down stroke and of each up stroke. A stirrup attached to the regulator was jerked to and fro by a λ, or forked tumbler bob, fixed to the same shaft, as were two tappets struck by pins in the plug rod. The F-shaped injection cock handle was held by a catch till tripped by a rod projecting from a buoy floating on the surface of water inside a pipe passing through the top of the boiler. A pause, whose length depended on the pressure in the boiler, would ensue with the piston at the top of the stroke. The injection cock was replaced in its catch by a pin in the plug rod. The print affords evidence that the duty of tripping the injection cock had been, at the date of the print, transferred to the "scoggen," a hinged bar struck by a pin in the plug rod. The pause at the top of the stroke was suppressed so that a greater number of strokes were made in a given time; this would explain Reference 13, "Scoggen and his Mate, who work Double to the Boy, γ is the Axis of him."

The table of references shows that the cylinder of the engine was of brass, 21 in. diam., 7 ft. 10 in. long, supported above a boiler 5 ft. 6 in. diam., and 6 ft. 1 in. high, containing 13 hogsheads (700 gall.). The pump work was in two lifts, each of 75 ft. M. 4069.

43. Photograph of an engraving of Newcomen's engine. Presented by R. L. Galloway, Esq., 1880.

This engraving is from the same plate as the preceding (No. 42), but the letterpress is arranged differently, being in one column only. From some contemporary MS. notes which appear on the print, it appears that the beam "vibrates 12 times in a Minute, and each stroke lifts 10 gall. of water 50 yards perp^{r}.," which is equivalent to 5·5 h.p. in useful work done.

M.2570.

44. Model of a Newcomen engine (working). Made in the Museum, 1891. Plate I., No. I.

This is a full-sized copy of a model, now in the Museum of King's College, London, and probably made by Dr. J. T. Desaguliers about the year 1740; in a few unimportant details the original, which is now imperfect, has not been followed absolutely.

The machine consists of a boiler, 8·75 in. diam., directly above which is a vertical cylinder fitted with a piston, 2·25 in. diam. by 7·75 in. stroke. A chain from the piston is attached to one end of a beam capable of swinging on a central gudgeon. To the other end of this beam a similar chain is secured, and carries the pump rods which are connected with the buckets of two vertical pumps, 1·25 in. diam., which divide the total lift into stages. Both the steam valve and the injection cock are actuated by pins in the plug rod. The method of working will be understood from the description above (*see* No. 41).

The following table shows approximately the best results obtained at various dates as the steam engine subsequently developed, the figures giving the "duty" or foot-pounds of water pumped for every 112 lb. of coal consumed:—

1718.	Newcomen	4·3	millions.
1767.	Newcomen, Beighton and Smeaton	7·4	„
1774.	Smeaton	12·5	„
1774.	Watt (separate condenser)	21·0	„
1778.	Watt (separate condenser	31·0	„
1800.	Watt (separate condenser and expansion)	66·0	„
1842.	Cornish engine and boiler, with high pressure	100·0	„
1883.	Waterworks engine (two stage expansion)	120·0	„
1907.	Waterworks engine (three stage expansion)	152·0	„

Notwithstanding their low efficiency, Newcomen engines are still working at one or two collieries where waste coal is available. M.2421.

45. Photograph of a print of a Newcomen engine (1725). Presented by R. B. Prosser, Esq., 1906.

This is a reproduction, reduced in size, from a copper-plate engraving dated 1725, preserved at the British Museum, which has, at the sides, the letterpress shown.

It is interesting as showing the advances made in the interval between the engine erected near Dudley Castle in 1712 (*see* No. 42) and this one. The boiler is fed partially with the hot water coming from the bottom of the cylinder, and as a result the number of strokes has increased from the 10 or 12 strokes previously known to about 16 per min. There are two gauge cocks to the boiler, which enable both high and low water to be tested; there is also a dead-weight safety valve. An independent jack head pump, instead of the plug rod, supplies the injection water cistern. The valve gear has the buoy arrangement (*see* No. 42). M.3468.

46. Drawing of Newcomen engine, near Bristol. Received 1895.

This engine, which is believed to have been built in 1750, was used for draining a coal pit 750 ft. deep at Bedminster, a duty which it successfully performed by working three or four hours a day till 1900, when it was dismantled. Steam was originally supplied by two haystack boilers, but reduced steam from a later boiler had been used since they became unserviceable.

The cylinder was 66 in. diam. by 6 ft. stroke, and weighed with its conical base about 6 tons. The piston was packed with rope weighted with pig-iron, and had three rods and chains connecting it with the arch-head at its end of the beam. The beam was of oak trussed with iron, and weighed about 5 tons; its length was 24 ft., and depth 4 ft. At the base of the cylinder were its three valves: a circular lift-valve for the steam, a slide for the injection, and a clack for the condensed water. At the pump end of the beam were three chains connected with three lift-pumps of 9·75 in. diam., one delivering into another so as to divide the lift into three stages. The jack-pump was worked by a separate chain attached to the main piston. The engine, making ten double strokes per minute, indicated 52 h.p., while the water pumped represented about 44 h.p. It is thermally rather than mechanically that such engines are inefficient. M.2570.

See "Engineering," 1895, i. p. 505.

47. Photographs of Newcomen engine in Fairbottom Valley, Lancashire. Received 1900.

These prints show with considerable detail the pumping engine known as "Fairbottom Bobs," erected at Bardsley between Ashton-under-Lyne and Oldham, as it appeared in 1860 or later. Little is known of the history of the engine, but it is generally reported to have been built in 1750, and to have been re-erected at Bardsley about the end of the 18th century, where it worked till 1827, pumping from the Cannel Mine at a depth of 225 ft.

The cylinder is 27·4 in. diam. by 6 ft. stroke, and is a single casting; air was prevented from leaking past the piston by a packing of peat or hemp, and the injection jet discharged directly into the cylinder. The beam is 20 ft. long, built up of two 12 in. by 14 in. oak timbers trussed with iron, and its bearings are supported by a masonry pillar 14·5 ft. by 7·25 ft. at the base Steam was supplied by the wagon boiler, 6·25 ft. wide, 7 ft. high by 17 ft. long, shown in the photograph, but it is probable that the original boiler was of the haystack form. M.3114.

48. Photographs of a Newcomen pumping engine. Presented by Messrs. James Joicey & Co., 1891.

This atmospheric engine was built in 1754 by the Coalbrookdale Iron Co. and erected at the Tanfield Moor Colliery, Durham. It had an open-topped cylinder 48 in. diam., and a stroke of 7 ft. indicating probably about 35 h.p. It lifted water from the Hutton Seam at a depth of 393 ft. into the delivery drift at 174 ft. below the surface, giving an actual lift of 219 ft. It stopped pumping in 1876, and these photographs were taken in 1891 when the engine was being dismantled. In one view the old haystack form of boiler is seen.

Since starting, the engine had been considerably modified by the removal of the original wooden beam and arch-heads, these being replaced by a cast-iron beam and Watt's parallel motion. M.2375.

49. Drawing of atmospheric engine at Cronstadt. (Scale 1 : 36). Woodcroft Bequest, 1903.

This longitudinal section represents the Newcomen engine, designed by Smeaton in 1773, constructed at Carron Iron Works, and erected at Cronstadt in 1777 for emptying the graving docks. These docks had been commenced by Peter the Great in 1719 and completed in the next reign, but they were of little use owing to the two pumping windmills provided to discharge them proving unequal to the work. Smeaton's engine was similar to that which he and the Carron Co. had constructed in 1775 for Chacewater Mine, in Cornwall, but was rather smaller; another similar engine was at the same time erected at the Carron Works where it remained intact till 1873.

The Cronstadt engine was of about 100 h.p., having a cylinder 66 in. diam. by 8·5 ft. stroke, an effective pressure on the piston of 8·3 lb. per sq. in., and making from 10 to 13·5 double strokes per min. It worked two pumps side by side each 26 in. diam. with the same stroke as the cylinder, and the height of lift varied from 33 to 53 ft., so that about 60 h.p. was the useful capacity of the plant. The injection pump, 11 in. diam. by 5 ft. stroke, raised water to a cistern which was at the top of the engine house 52 ft. higher. The links of the four chains were of cast iron, each 4 in. by 2·37 in. in section; the pins were of wrought iron 2 in. diam. and the load was distributed between the chains by equalising links. The beam was built up of 20 balks of fir, the four centre ones being 12 in. sq. and the outer ones 12 in. by 6 in.; these were bent to enclose the axle and held by straps, through bolts and wooden keys.

Three cast-iron boilers were provided, of a type then frequently employed; they were of the haystack form and all joints were made by flanges and bolts. Each boiler was 16·3 ft. high by 10 ft. diam., had a grate area of 20·2 sq. ft., and weighed 15·5 tons. M.3288.

50. Drawing of Newcomen engine at Kilmarnock. Presented by Robert Kennedy, Esq., 1898.

The engine represented was erected in 1806 at Caprington Colliery, and was at work occasionally as late as 1901, when it was removed to the Dick Institute at Kilmarnock. The original timber beam with horsehead ends and chains was, however, replaced about 1850 by the present cast-iron beam with Watt's parallel motion.

The open-topped cylinder is 30 in. diam. by 63 in. stroke; the main pump is 9 in. diam. by 63 in. stroke, and had a lift of 170 ft. The jack-head, or boiler-feed, pump and the service pump are both 5·875 in. diam. by 31·5 in. stroke. The boiler pressure was 0·5 lb. per sq. in., and during condensation the cylinder pressure fell to 8·5 lb. below atmospheric; the mean value was 7·16 lb. The engine made twelve working strokes per minute, and indicated 9·65 h.p., while the pump indicated 8·32 h.p. A copy of an indicator diagram taken in 1897 is attached. M.3032.

51. Drawing of pumping engine proposed by Leupold.

Jacob Leupold, in 1724-7, published a sketch and description of a proposed high-pressure engine for working a force pump. There were to be two vertical single-acting steam cylinders, two pumps and two rocking beams; but the steam and exhaust for both cylinders were to be controlled by a single four-way cock, so that the cylinders worked alternately. The weight of each steam piston was to exceed that of the pump plunger at the other end of its beam so that the in-strokes would be done by gravity, while the exhaust steam passed into the atmosphere.

The use of a non-condensing engine and of a four-way cock, which Leupold pointed out could be worked automatically, are the leading features in this proposal. M.2557.

52. Original experimental model of a separate condenser, made by James Watt, 1765. Watt Collection, 1876. Plate I., No. 2.

This, although incomplete, probably shows the original apparatus by which Watt demonstrated the soundness of his first invention in connection with the steam engine, the subject of his patent of 1769.

It consists of a steam jacketed cylinder 1·4 in. diam. fitted with a hemp-packed piston. From the piston a rod passed downward through a gland and terminated in a hook from which a weight of 18 lb. was suspended. At the side of the cylinder is a vertical pipe closed at the top, but opening into the cylinder, and secured below into a metal box. From the top of this box

also passes upward a vertical tube which was the barrel of the air-pump. From the the top of the closed vertical tube—which is the separate condenser—projects a small tube closed by a snifting valve, opening outward. The condenser and air-pump were enclosed in a cistern of cold water, and the air-pump was fitted with a piston. A sectional drawing of the apparatus is attached.

For some unknown reason the model is now soldered together in an unworkable manner. Possibly Watt, after his experiments and before his patent was secured, felt that the model might fall into dishonest hands, and therefore left it in this misleading shape, with the steam jacket opening into the condenser and the hole in the cylinder end, and at J soldered over. That the condenser pipe E originally joined the cylinder at the now closed hole at J is proved by the curved notch filed in the cylinder cover, which notch is now purposeless, but would be necessary with the condenser in the higher position; the short pipe from J into the cylinder also admits of no other explanation. Steam to the jacket entered at B, and there is a small hole in the lower cover of the cylinder to act as a drain. By a cock, steam was admitted into the cylinder through the now closed hole in the top cover, and filling the cylinder it blew through into the upper part of the condenser and out at the snifting valve at G. When all air had been so displaced the steam cock was shut and the piston in the air-pump H was pulled up by hand, thus leaving an exhausted and cold chamber at F into which the steam from the cylinder rushed and was immediately condensed. As the weight then lifted by the piston was 18 lb., the condenser pressure was nearly 12 lb. below that of the atmosphere, corresponding to a vacuum of 24 in. of mercury. M.1823.

53. Original model of a surface condenser, made by James Watt. Watt Collection, 1876. Plate I., No. 3.

This model, which was probably made very shortly after No. 52, is complete, and shows an excellent surface condenser and air-pump. The condenser is circular, and is traversed by 140 small tubes soldered into a metal tube plate at each end. The cooling water passes through the interior of the tubes. A vertical air-pump is attached to the side of the casing, and consists of two tubes united below. The shorter one is the barrel of the air-pump and is fitted with a solid piston. The longer one is fitted with a delivery valve at the top, and a suction valve where it is connected with the lower end of the condenser. The exhaust steam entered the upper portion of the condenser, and the lower outlet opened into the column of the air-pump in such a way that the rising and falling of the water column with the motion of the air-pump piston removed all air from the condenser, and delivered it before discharging the water. In this way an excellent vacuum would be maintained, and modern engine air-pumps are only found efficient when they accord with the principles here observed by Watt.

Through the difficulty found in maintaining this form of condenser tight, Watt soon discarded it for the jet form, but now with improved methods of construction the tubular surface condenser is the form most in use, chiefly owing to the supply of pure water that it gives ready for returning into the boiler. M.1824.

54. Photograph of early Watt engine. Presented by G. R. Jebb, Esq., 1898.

This engine was constructed in 1776 by Messrs. Boulton and Watt for the pumping station of the Birmingham Canal Navigation at Rolfe Street, Smethwick. It is believed to be the first engine sold by the makers, and is the oldest in existence embodying Watt's first improvement on Newcomen's engine.

The engine was worked regularly till 1892, and occasionally afterwards till 1898, when the house was demolished, and the photograph taken, prior to the removal of the engine to its future resting place at Ocker Hill, Tipton, where

it is being preserved in working condition. The cylinder is single-acting, 32 in. diam. by 8 ft. stroke; the beam is of timber with horsehead ends and iron tie rods. M.3036.

55. Portions of an early pumping engine. Presented by Messrs. Branson and Gwyther, 1861.

These formed a portion of the engine "Old Bess," which was erected at Matthew Boulton's hardware factory at Soho in 1777, and remained in use till 1848, when the business was discontinued. The portions preserved comprise the steam cylinder with its piston and rod, one length of the pump barrel, the complete beam with its chains, and the main bearing. A full description of the engine is given in No. 56.

Upon the engine being dismantled a small furnace was discovered beneath the steam cylinder. Such a furnace was added in the very early engines to re-evaporate the water which condensed in the steam case, with the object of reducing the steam consumption. M.317.

56. Model of the "Old Bess" engine (working). (Scale 1 : 12.) Made in the Museum, 1894. Plate I., No. 4.

This model, which has been constructed from the data given by the existing portions of the engine, together with those on two early drawings, shows the general arrangement of the engine erected at Boulton's works at Soho in 1777. It embodied the first improvements made by Watt upon Newcomen's pumping engine.

James Watt's first steam engine was constructed and tried at Kinneil in Scotland in 1769, and was sent to Birmingham in 1773. At Kinneil the engine, although it had a separate condenser (*see* No. 52) and embodied other improvements, was hardly a success owing to its defective mechanical construction. When Watt joined Boulton the engine and boiler were conveyed from Scotland by water *viâ* Hull to Birmingham, and for two years the engine was being rebuilt and improved, until, with a new bored cast-iron cylinder, it worked fairly well. It was known as "Beelzebub," and had an 18 in. cylinder, 5 ft. stroke, and worked an 18·5 in. pump against a 24 ft. head. In 1777 it was destroyed by fire, but "Old Bess" was constructed immediately afterwards to do the same work as the destroyed engine; it was, however, of considerably more power, as the steam cylinder is 33 in. diam. with a 7 ft. stroke, and the pump has a diam. of 24 in.

Matthew Boulton, when James Watt first knew him, was an extensive manufacturer of ornamental articles, and to drive his metal rolls and polishing machinery utilised the power of two water-wheels, which, in dry weather, were assisted by from six to ten horses. The pumping engine "Beelzebub" and afterwards "Old Bess" were constructed to pump water from the tail-race back into the head-race of a water-wheel of 24 ft. diam. and 6 ft. breast, at times when the stream flow was insufficient. This indirect method of obtaining rotatory motion by steam power had previously been employed in London and elsewhere. Long after the introduction of the rotative steam engine, however, this method of driving was still practised for textile machinery, owing to the more regular motion that it was considered was obtainable by the intervention of a water-wheel. The power lost must, however, have been considerable, for if the mechanical efficiency of the water-wheel and its gearing was 50 per cent. and that of the pumps 80 per cent., the combined efficiency could only be 40 per cent., which would be only one-half of the mechanical efficiency of a directly rotative engine, so that twice the amount of coal then necessary would be consumed in doing the required work. M.2559.

57. Model of a single-acting beam pumping engine. Watt Collection, 1876.

This is a working model of an engine resembling the present Cornish pumping engine, and in its arrangement and details is somewhat similar to the

"Old Bess" engine (*see* No. 56); but it is of later date, as both piston and pump-rod ends are guided by Watt's parallel motion. The condenser, which is very small, is arranged in a tank, and by its side is the air-pump, which is driven by a prolongation of the plug rod. The valve gear is of the latch type driven by tappets from the plug rod. The parallel motion for the plug rod is derived from the parallel point by an additional pantograph. The pump is in a large wooden tank, and has its bucket weighted with lead to represent the heavy spear rods of a mining pump. M.1804.

58. Drawing of Watt's single-acting pumping engine. (Scale 1 : 28.)

This represents the arrangement supplied by Messrs. Boulton and Watt in 1788, but it differs only in detail from the standard Cornish pumping engine since so extensively used.

The engine valves are of the drop type, connected by racks and segmental arms with levers struck by tappets on the plug or air-pump rod; the top valve admits steam to the cylinder, and was known as the "expansion" valve, as it was set to cut off steam at about half-stroke, thereby allowing the remainder of the stroke to be performed by the expansion of the steam previously admitted without further demand upon the boiler. The lower or "equilibrium" valve is opened when the piston reaches the bottom of its stroke, thus allowing the steam above the piston to pass to the lower side, so that by the weight of the pump-rods the piston ascends to the upper end of the cylinder. The lowest valve controls the passage from the lower end of the cylinder to the condenser, and is open throughout the down-stroke of the piston.

The well-known high economy of these engines is largely due to their acting somewhat as if compounded, since the upper portion of the piston and cylinder are never exposed to the low temperature of steam discharging into the condenser; the cylinder also has a steam jacket. The closed top cylinder here employed was introduced by Watt in 1774. The boiler shown is of the "wagon" type (*see* No. 350), and probably worked at about 5 lb. per sq. in. above atmospheric pressure. M.2557.

59. Sectional model of twin cylinder engine, by James Watt. Watt Collection, 1876.

This is a double cylinder engine in which both cylinders are single-acting, but have their piston rods connected by a chain, so that working alternately they are equivalent to one double-acting cylinder, a fact that Watt probably quickly realised, as there is no evidence that an engine resembling the model was ever constructed.

The chain passes over and is fixed to a grooved wheel carrying a crank pin at the back, which would drive a connecting or pump-rod. The upper ends of the cylinders are closed but in free communication, and a non-return valve in each piston will permit steam to pass upward into this space. Below each cylinder is an air-pump and condenser, the air-pump rods being connected by a chain passing over and fixed to a smaller wheel (now missing) on the overhead shaft. At the foot of each cylinder is a steam valve and an exhaust valve, by which communication is opened alternately with the boiler and the jet-condenser which is in the eduction pipe leading to the air-pump. M.1820.

60. Models of an inverted cylinder pumping engine, made by James Watt. Watt Collection, 1876.

This arrangement of direct-acting pumping engine was proposed by Watt in 1765–6 when introducing his separate condenser, but abandoned in favour of the beam construction adopted by Newcomen. It is now usually known as

the "Bull" engine, owing to its having been introduced and constructed on a practical scale by William Bull and his son Edward, who, in conjunction with Trevithick, erected several important pumping plants in Cornwall. They were, however, infringing Watt's patents, and in 1793–5 were stopped by legal proceedings.

The cylinder is supported over the pumping shaft by beams extending across the engine house, and the piston rod passes through the bottom of the cylinder and is directly attached to the pump spears, the weight of which performed the downward stroke of the pump (*in the model it is assisted by a leaden weight*). Beneath the cylinder is a short rocking beam by which some of the weight of the spears is counterbalanced, and from which the motion for the valve gear and air-pump is obtained.

From the sectional model it is seen that the exhaust pipe is provided with a jet and used as a condenser, which is cleared by a vertical air-pump; the jet is, however, intermittent, being controlled by the valve gear so that it is only turned on during the exhaust stroke. M.1806 & 1806A.

Rotative Engines.

61. Model of sun and planet gearing, made by James Watt. Watt Collection, 1871.

Watt was working on the application of the crank and connecting rod to an engine beam as a means for converting its reciprocating into circular motion when he was forestalled by the patent taken out in 1780 by James Pickard, who, it is generally thought, obtained his information through one of Watt's workmen; Watt, instead of contesting the patent, decided to adopt other mechanism. This and the four succeeding models show some of these mechanisms which he patented in 1781; of these, however, only the sun and planet gear came into use.

It is an epicyclic gear consisting of a "sun" wheel keyed on the end of the fly-wheel shaft and a "planet" wheel bolted to the connecting rod end and held in gear with the sun wheel by a link loose on their centres, as in the model, or by a pin in the centre of the planet wheel moving in an annular slot. When both wheels are of the same diameter the fly-wheel makes twice the number of revolutions that it would if actuated by a crank and connecting rod, the extra revolution being due to the fact that the planet wheel, although going round in a circle, does not revolve on its own axis. In some of Watt's engines the diameter of the planet wheel was less than that of the sun wheel, and in this way shaft speeds were obtained only about 50 per cent. greater than would have been the case with a simple crank. M.1811.

62. Model of a ladder connecting rod, by James Watt. Watt Collection, 1871.

This model shows another of the mechanisms schemed by James Watt about 1781 as an equivalent for the crank.

The end of the connecting rod is made in the form of a rack or ladder, the rungs of which are capable of acting on either side of a pinion fixed on the fly-wheel shaft of the engine. The connecting rod is guided by a roller at the lower end, which works in a large opening of special form in a fixed guide plate which keeps the rack in gear with the pinion on the fly-wheel shaft. The arrangement somewhat resembles the mangle-wheel motion reversed. M.1789.

63. Model of a ladder connecting rod, by James Watt. Watt Collection, 1871.

This shows a mechanism similar to that of the adjoining model; it was schemed about the same time and for the same reason. It shows a connecting rod with a rack at the end composed of rungs capable of acting on either side

of a pinion fixed on the shaft of the engine. The rod is kept in gear during a portion of each stroke by two fixed pins or rollers outside the rack, while on turning the dead centres, projecting pins, one at each end on opposite sides of the rack, are guided by the curved edges of plates fixed to the framing.

M.1790.

64. Models of internally geared connecting rods, by James Watt. Watt Collection, 1871.

These models show another of the mechanisms patented in 1781 by James Watt as an equivalent of the crank. The connecting rod end is formed into a large internal spur wheel which gears with a spur wheel on the fly-wheel shaft, the teeth being kept in gear by means of a roller at the lower end of the connecting rod which works on a fixed oval-shaped guide block below the shaft.

N.B.—The oval shape of the connecting rod ends is a distortion due to shrinkage of the wood. M.1790A.

65. Model of a crown cam motion adapted to a winding gear. Watt Collection, 1876.

This shows another of the mechanisms patented in 1781 by James Watt as an equivalent of the crank.

A connecting rod from the engine beam rocks an equal-armed lever having two conical rollers mounted on it, one at either end. The centre on which the lever moves is close to a vertical shaft on which are mounted a crown cam of considerable throw and a heavy fly-wheel. By the reciprocation of the engine beam, the conical rollers are caused to press upwards alternately against the edge of the crown cam and through the inclined action cause it to rotate. The fly-wheel is for the purpose of carrying the cam over its dead centres. A spur pinion on the fly-wheel shaft gears into a large spur wheel formed on the winding drum. M.1821.

66. Original indenture. Presented by Messrs. J. S. Smith, Druce & Co., 1908.

This indenture of agreement made March 1st, 1786, between James Watt and Matthew Boulton of the one part and Samuel D. Liptrap and partners of the other, is for the erection and maintenance by the latter of a double acting rotative beam engine at a distillery near Whitechapel Road (*i.e.*, where Durward Street now stands) and for the payment to the former of an annual premium of 63*l.* during the unexpired term (*i.e.*, of 14 years) of Watt's patent. The engine was to be of 10 h.p., having a cylinder 17 in. diam. by 5 ft. stroke, to be used for grinding malt or other grain and for pumping water, "worts" and "wash."

Boulton and Watt sold their pumping engines on a royalty of one-third of the saving in coal resulting as compared with an atmospheric engine doing the same work, and on the introduction of their rotative engine adopted a "premium" similarly calculated on the saving resulting as compared with the power (*e.g.*, of horses) which was replaced. M.3542.

67. Boulton and Watt's rotative engine. Presented by Matthew Piers Watt Boulton, Esq., 1861. Plate I., No. 5.

This engine was erected at Soho, near Birmingham, in 1788, where it was known as the "Lap" engine, from its driving the machinery for lapping or polishing steel ornaments. It is an early example of Watt's double-acting rotative beam engine, with separate condenser and air-pump. It was nominally a 10 h.p. engine, but indicated 13·75 h.p. It continued to work till 1858, and three years later it was removed to South Kensington.

The cylinder is 18·75 in. diam. and 4 ft. stroke; the fly-wheel, 16 ft. diam., has a mortised toothed rim and drove two pinions 3 ft. diam. from the shafts of which motion was communicated by belts or gearing to 43 metal working machines. It has a sun and planet motion (*see* No. 61) for driving the shaft, and tappet gear to the valves, worked by the plug frame or air-pump rod, the tappets on the rod striking the levers connected with the valves in such a manner that when one valve was closed by the tappet another valve was opened by being freed from a catch or hook that had before held it closed. The connecting rod acts in a direct line to the planet wheel, and is slightly bent in an S curve to clear the sun and planet wheels. There is a slow speed centrifugal governor driven by a chain and pulleys; it acts upon a throttle valve of the disc type. The framing is entirely of wood bound together in a rather primitive manner by straps and bolts. The beam is of wood also, the main gudgeon being placed beneath the beam and not through it. M.318.

68. Model of a beam engine with sun and planet motion. (Scale about 1 : 8.) Received 1869.

This represents an early double-acting rotative engine. The framing, the beam, and the connecting rod are of wood. Watt's parallel motion and his sun and planet gear (*see* No. 61) are fitted. To obtain a straight line motion for the air-pump rod and to avoid fouling the rods of the main parallelogram, the latter is extended as a pantograph to give a guided point for attaching the rod. Tappets on this rod strike a fork keyed to an internally toothed segment gearing with teeth on the plug of a four-way cock for admission and exhaust of steam to the cylinder. An engine embodying this valve gear but with cast iron, etc., beam, was built in 1808 at Southwark. A circular saw arranged on a bench is driven by a band from the engine. M.1175.

69. Sun and planet engine. Presented by G. Atkinson, Esq., 1885.

This engine was constructed by Messrs. Boulton and Watt, and erected in 1797, for John Maud, chemist and druggist, at 66, Aldersgate Street, E.C., subsequently Atkinson's Chemical Works, where it continued working until 1885, when it was taken down and presented to the Museum. The engine was of 8 nominal h.p., and had a cylinder 16 in. diam. and 4 ft. stroke, but in 1806 it was altered by the makers to a 12 h.p. engine, the diameter of the cylinder being increased to 19·25 in.

It is a low-pressure condensing engine, with sun and planet gear, similar in general construction to No. 67, but the valves are driven by a crank motion instead of by tappets, and there is a separate cut-off valve moved by a cam motion to give expansive working. The crank and cam are both on a countershaft driven by spur gearing, at one half the speed of the fly-wheel shaft, which, on account of the sun and planet gear, makes two revolutions for each double stroke of the engine. The connecting rod from the valve crank-pin is made with a gab end, so that it can be disengaged, and the valves be worked by hand levers when required in starting the engine. The engine was probably made with a tappet motion in the first case, and the motion above described added at the later date. M.1620A.

70. Drawing of mill engine with sun and planet gearing. (Scale 1 : 16.)

This shows the standard type of factory engine constructed by Messrs. Boulton and Watt from 1787 till 1800. It represents a 10 h.p. engine built in 1795 for a starch works in Lambeth; it made 50 strokes per minute, and owing to the sun and planet gearing the fly-wheel made 50 revs. per min. These engines were made in various sizes up to 50 h.p., and two examples of the smaller sizes will be found in the Museum (*see* Nos. 67 and 69). M.2557.

71. Drawing of Symington's steam engine. Woodcroft Bequest, 1903.

This is a copy of the drawing enrolled with William Symington's Patent Specification of 1787, which shows an atmospheric engine in which heat losses are diminished by confining condensation to the lower and enlarged part of the cylinder by means of a free piston or air-pump bucket resting, close to the surface of the cold water there, on two rods supported by a lever worked by tappets in the plug frame. A valve in this bucket is similarly worked so that when the cylinder has filled with steam and the piston has gone outdoors, this valve is opened, admitting the steam to the underside of the bucket, which at the same time is raised by its lever. The injection water is also delivered into this space. When steam is again admitted it closes the valve in the bucket, forces the latter down and displaces air and condensed water. A few of these engines were built, as the arrangement was not considered to be an infringement of Watt's patent for the separate condenser.

The cylinder is jacketed by the hot gases passing through a helical flue on their way from the boiler to the chimney.

A method of transforming reciprocating into continuous rotative motion by means of two ratchets and of two racks suspended from the engine beam is shown. This mechanism and the engine are interesting, as they were used by Symington in very early experiments on steam navigation (*see* Marine Engineering Collection). M.1659.

72. Model of Newcomen rotative engine. (Scale about 1 : 8.) Received 1912.

This represents the atmospheric engine erected in 1790 in the "Crank Mill" at Morley, Yorks. This mill was the first in the neighbourhood to be driven by steam power, and the engine remained in use till 1875, about which time this rough model was made.

In order to meet the great demand that arose at the close of the eighteenth century for engines to turn mill work, those people who did not wish to pay the royalties for Watt's patent engine were obliged to adapt the Newcomen engine to work rotatively. The method finally adopted was to fit the outdoor end of the beam with a connecting rod to a crank on the mill shaft, to which was fixed a fly-wheel heavily weighted on the crank side, so as to store one half of the work done on the downward and restore it in the upward stroke. The flexible connection between the piston rod and beam was retained, but after 1798, when the patent for the parallel motion expired, this mechanism was usually added, as shown in the model. The cylinder is 2·2 in. diam., and the stroke 4·8 in. The steam and injection cocks are worked by tappets in a plug frame hung from the beam by a link and sliding in guides. The eduction pipe for condensed steam and air terminated in a hot well.

An adjacent photograph shows a similar engine used for winding at a colliery, and there is one so used at the present day. M.4148.

73. Model of a single-acting rotative engine. (Scale 1 : 8.) Lent by W. W. S. Westwood, Esq., 1894. Plate I., No. 6.

This shows a method of obtaining rotative motion from an open-topped cylinder provided with Watt's separate condenser. To get over the difficulty of there being only one working stroke per revolution, the connecting rod is so weighted as to store one half of the work done in that stroke and restore it during the idle stroke. It is true that Watt contemplated, in his patent of 1782, using an expedient of this kind for his single-acting engines, but it is difficult to believe that it was ever adopted, because his double-acting engine followed immediately after. Atmospheric engines, however, had to be so arranged to make them work rotatively (*see* No. 72). For pumping, a similar arrangement is known to have been adopted (*see* adjacent photograph).

The model bears internal evidence of having been made subsequent to 1800; it was for many years at Corbyn's Hall Ironworks, Staffordshire, whither it is said to have been sent from Soho Foundry. It was at one time used for driving a lathe. The cylinder is 2·6 in. diam. and the stroke 3 in.; the piston rod is guided by Watt's parallel motion (1784), but the air-pump rod is hung from the end of the radius rod, instead of from a parallel point. The condenser and air-pump stand in the hot well; the former has a cock on the side and a drop valve, by which the injection could be regulated. The steam and exhaust drop valves are driven by a countershaft from an eccentric, a mechanism introduced for this purpose by Murdock in 1800. M.2657.

74. Motion diagram of a beam engine. Watt Collection, 1876.

This shows the mechanism of a rotative beam engine, similar to that represented by the models Nos. 75 and 76, in which the steam is distributed by a long D slide valve actuated by an eccentric. It was probably made when the introduction of this improved arrangement of valve gear was under consideration, for it is recorded that Watt preferred the four drop valves employed in his earlier engines, and that he somewhat reluctantly consented to the adoption of the simpler slide valve of Murdock. M.1807.

75. Model of a double-acting beam engine (working). Watt Collection, 1876.

This model was probably made about the year 1800, as the valve gear and general arrangements are improvements upon those in the actual engine, No. 69, erected in 1797. The framing is of timber, supported under the beam gudgeon by a metal column carried on a masonry pedestal. The beam is a casting, and has its terminal pins carried in trunnion hoops which adjust themselves to any inaccuracy in the erection. The valves are of the drop type, two for each end of the cylinder; the stem of the lower valve passes through the tubular stem of the upper one, rendering only one opening into the steam box necessary while simplifying the mechanism. The valves are driven by a quiet tappet gear from a horizontal shaft rocked by an eccentric on the crank-shaft, but the valve gear does not permit of expansive working.

The beam is fitted with Watt's parallel motion, and by the looping of the lower tie rod the air-pump rod is directly connected with the parallel point, in the way that has since been generally followed. The condenser is cylindrical and is enclosed in a water tank. To the top of the condenser is secured the air-pump, the discharge of which is led off by a shoot. The injection water is conveyed to the condenser by a horizontal pipe from outside the tank. The top cover of the air-pump is guided as in No. 76. The steam cylinder is 1·625 in. diam. by 4·5 in. stroke. M.1805.

76. Model of a beam engine (working). (Scale about 1 : 8.) Lent by C. W. Osman, Esq., 1859.

This model was made by William Tongue, while an apprentice with Messrs. Boulton and Watt at Birmingham, 1797–1804 (*see* facsimile of his indentures on the wall).

The general arrangement including the valve gear is similar to No. 75. The valves are of the tubular or "socket" type, introduced by William Murdock, rendering only one opening into each valve box necessary. The straight line motion of the air-pump rod is obtained from a pantograph extension of the main parallelogram as in No. 75. This was discarded for the simpler plan, which subsequently became general, of attaching the rod to the "parallel" point and looping the tie rod to clear it. The condenser is contained in a large rectangular tank situated under the cylinder. This tank also contains the air-pump which is provided with a cover carrying a stuffing-

box through which the pump rod passes. The latter, by the friction of the packing, lifts the cover as far as permitted by three guiding stops, and is similarly lowered on the down stroke, an arrangement equivalent to a mechanically-moved delivery valve. M.319.

77. Cabinet steam engine, by James Watt (working). Contributed by A. Greg, Esq., 1858.

This engine was the property of James Watt, who bequeathed it to Mr. John Kennedy, of Manchester; it may be said to represent the steam engine as left by Watt. It is a small double-acting beam engine with a separate jet condenser and air-pump. The slide valve is of the long D form; the cylinder is steam-jacketed. Watt's parallel motion is employed to guide the top of the piston-rod and the air-pump rod. The simple crank and connecting rod is used to secure rotative motion. The slide valve is worked by a single eccentric, and the speed of the engine is controlled by Watt's conical pendulum governor, which acts on a throttle valve in the steam passage. The cast-iron tank, standards, and beam, together with the general arrangement of the engine, hardly differed from those of similar engines of 50 years subsequently. Inv. 1858–1.

A similar small engine (working) is shown in a neighbouring case. M.962.

78. Sectional wooden model of beam engine (working). Made in the Museum, 1866.

This is a copy in wood of Watt's rotative beam engine adjacent, sectioned to show the internal construction. It also serves to illustrate, generally, the construction of the cylinder and valves of the later beam engine in an adjoining case.

The cylinder jacket through which boiler steam passes on its way to the valve chest, the slide valve, the jet condenser, and the air-pump can be clearly seen. The valve is of the long D type, which was patented in 1799 by William Murdock, of the firm of Boulton and Watt, but which was not introduced till after 1800, when Watt, who preferred the drop type of valve, had retired. The live steam is always round the waist of the valve. The exhaust from the upper end of the cylinder passes to the condenser through the tubular centre, the exhaust from the lower end passing directly to the condenser. M.1002.

79. Model of oscillating engine (working). Lent by W. Murdock, Esq., 1894. Plate I., No. 7.

This is the original model constructed in 1785 by William Murdock at the Soho Works. The cylinder is 1·5 in. diam., 4 in. stroke, and double-acting. It is made of wood, and so was probably tried only with compressed air—a method of driving that was afterwards practically adopted by Murdock for power transmission. The framing consists of two "A" frames well braced together and supporting the shaft, which is furnished at one end with an overhanging crank, and at the other with a large fly-wheel. The crank pin is directly attached to the piston-rod—the cylinder oscillating on central trunnions. The outside trunnion is that through which the working fluid is introduced, while the other is merely a mechanical support. From the inlet passage the driving fluid passes by a channel to a valve chest on the side of the cylinder. The valve is a long piston of square section greatly reduced in the centre, which is the steam space. The exhaust escapes by the open ends beyond the valve. The valve spindle is continued upward, and by a V-shaped link is attached to a stationary point on the same level as the trunnions. The oscillation of the cylinder causes a longitudinal motion to the valve which gives a simple distribution of steam, but one which is not quite equal in both

strokes. An eccentric in the middle of the crank-shaft drives a small pump through the intervention of a lever which is so arranged as to double the stroke.

Although the model worked satisfactorily, it was forty years later before the merits of this type of engine were fully realised as the most compact arrangement for driving paddle-wheels, and for many other purposes. At the time the model was made, Watt was employing the sun and planet gear to avoid using a crank. M.2554.

80. Drawing of Watt's semi-rotary engine. (Scale 1 : 16.)

This is copied from Watt's patent specification of 1782; in the Watt room at Heathfield Hall, however, there is an unfinished model of this engine, which was commenced in 1765 or 1766.

The engine has a short horizontal cylinder with a radial piston which can swing through an arc of 240 deg. The lower sector of the cylinder is fitted with a stationary abutment block through which steam is admitted to either side of the piston, alternately. Below the cylinders are valve boxes for the distribution of the steam, while beneath these is a jet condenser, and two air-pumps which are driven by racks from a pinion on the vibrating shaft. A large spur wheel on this shaft has two racks gearing with it, and these move the rods of the two pit pumps that the engine was designed to work; by this latter arrangement the pump-rods mutually counterbalance. M.2557.

81. Drawing of bell-crank engine. (Scale 1 : 8.)

This arrangement of engine was introduced by Messrs. Boulton, Watt & Co. in 1799 to 1806; it was designed with the object of obtaining an engine that was self-contained, and more compact than the established beam engine.

The cylinder is vertical and double-acting, and by two vertical return connecting rods oscillates the horizontal arm of a bell-crank. From the vertical arm of the bell-crank a horizontal connecting rod proceeds to a crank on the fly-wheel shaft. A vertical air-pump is provided and is driven from the bell-crank. The engine foundation and the condenser tank are formed by one casting which carries the crank-shaft bearing. The steam is distributed by a long D-slide valve worked by an elliptical cam bolted to the fly-wheel arms.

These engines were made of from 4 to 8 h.p.; one was supplied in 1805 for Robert Fulton's paddle steamer "Clermont"; another was in use at the Soho works till 1896. M.2557.

82. Diagram model of a bell-crank engine. Watt Collection, 1876.

This is a similar engine to that represented in the drawing, No. 81, and was probably prepared to test the general convenience of the arrangement.

The valve shown is of the long D-type, but is driven by an intermediate lever from an eccentric on the fly-wheel shaft; the eccentric is slotted so that its position can be adjusted.

Those portions of the model made in polished brass have been constructed in the Museum to replace pieces not preserved. M.1808.

Nos. 83 *to* 99.—*These models are here inserted as forming part of the Watt Collection, but in some cases they are not directly related to the invention of the steam engine. They were presented in* 1876 *by Gilbert Hamilton, Esq., in the name of Messrs. James Watt & Co.*

83. Model of beam and connecting rods. Watt Collection, 1876.

In this model the horizontal lever, which probably represents an engine beam, is, by two connecting rods, coupled to two beams working in a vertical plane, at right angles to the main beam; universal joints at each end of the connecting rods give the requisite freedom. M.1803.

84. Model of flour mill driven by sun and planet gear. Watt Collection, 1876.

One of the earliest of Watt's double-acting rotative steam engines was set to work in 1786 at the Albion Flour Mills, in Southwark, and possibly this and the succeeding model were made when that enterprise was under consideration. The mill was a success and did much to popularise the steam engine, but was destroyed by incendiarism in 1791.

In the model the engine beam transmits its motion by a connecting rod to two sun and planet motions, the driven shafts being in one line and each having a fly-wheel. Each shaft drives a set of three pairs of stones by a bevel wheel on the fly-wheel shaft gearing with a bevel wheel on the vertical shaft, which also carried a spur wheel gearing with three pinions, one on each of the mill spindles. The backlash of the sun and planet gearing is greatly reduced by using double wheels forming step gearing, also the planet wheels are only half the diameter of the sun wheels. M.1791.

85. Model of a flour mill driven by a crank and connecting rod. Watt Collection, 1876.

In this model an engine beam transmits its power by a connecting rod which works on a crank pin placed between and carried by two fly-wheels on shafts which are in the same straight line. The shaft on one side transmits its motion through bevel wheels to a vertical shaft carrying a spur wheel gearing with the pinions on the shafts of the three mills arranged above it. The three pairs of stones of the opposite side are driven in the same way through the other fly-wheel shaft. M.1792.

86. Model of rolling and slitting mill. Watt Collection, 1876.

The plate rolls are driven through two fly-wheels by two connecting rods from the beam of an engine fitted with sun and planet motion, having stepped spur wheels. The main bearings of the beam have top caps, thus indicating that the cylinder used would be double-acting. The slitting rolls are driven by fly-wheels gearing with those on the plate rolls. M.1793.

87. Model of a rolling mill. Watt Collection, 1876.

This mill is driven by the connecting rod from the beam of a double-acting engine, fitted with a sun and planet motion, having stepped spur wheels.

As Boulton's works were largely engaged in manufacturing sheet metal, this and the preceding model were probably made before undertaking improvements in the plant by the substitution of steam for water power, and were prepared by Watt while testing the practical applicability of the sun and planet motion to this description of work. M.1794.

88. Model of spur gearing. Watt Collection, 1876.

This is a wooden model of a complicated train of gearing, the purpose of which is unknown, although it probably relates to some machinery for metal rolling. It was to be driven by a beam engine, the cylinder, main gudgeon,

fly-wheel and crank-shaft of which are represented. A two-speed gear is introduced, so that the effort of the engine may be further increased when on heavy work. M.1802.

89. Disconnecting cranks. Watt Collection, 1876.

The arrangement consists of two discs facing one another, one of which carries the crank pin and the other is secured to the shafting. Connection between the discs is made by three hinged tongues attached to the crank plate, and capable of being dropped into three notches in the driving disc, springs retaining these tongues in the closed or open position. An unfinished specimen of this gear is also shown. M.1818.

90. Experimental beams. Watt Collection, 1876.

These models were probably made by Watt when designing beams for his steam engines, as there is evidence that at first the engine beams gave trouble through their insufficient strength and rigidity.

The smaller beams have parallel top and bottom booms, with diagonal timber struts inclined at 60 deg.; in one case the tie bolts are inclined, and run axially through the timber struts, while in the other vertical iron tie bolts are used. In the latter case the model has been loaded to destruction.

The two larger beams consist each of a lower timber beam with a built-up truss above, the chief difference between them being that in one all the members are in duplicate. They have gudgeons and hooks or staples attached by which their strengths could be experimentally determined. From their trussing it is evident that these beams were designed for single-acting engines. M.1798.

91. Model of a beam engine frame. Watt Collection, 1876.

This model shows a complete timber framing for a beam engine. It consists of two rectangular frames, slightly inclined together at the top, and with the upper horizontal members supported under the bearings of the engine beam by two inclined struts. The main bearing for the crank-shaft is carried by an independent trestle similarly supported, and connected with the main framing. M.1799.

92. Model of a marine engine frame. Watt Collection, 1876.

This is a model in wood and metal of a massive iron framing for an oscillating cylinder engine. It is probably of much later construction than the other Watt models. M.1800.

93. Model of a forge hammer and a tilt hammer. Watt Collection, 1876.

These are both driven by one heavy cam on an engine shaft, the forge hammer being lifted by the belly and the tilt hammer by the tail; there is provision for a spring beam over the forge hammer, to cause it to deliver a greater blow than it would by gravity alone. This model has no top cap to the main gudgeon of the beam, and the cylinder end of the beam terminates in a curved segment, or "horse head," for the reception of a chain from the piston-rod, thus indicating that the engine was only single acting. M.1795.

94. Model of a pair of tilt hammers. Watt Collection, 1876.

In this model two engine beams, by connecting rods, drive cranks placed nearly at right angles on a horizontal shaft that carries two six-pointed cams. Each cam trips the end of a tilt hammer shaft, arranged on a fulcrum placed between the hammer head and the cam, the fall of the hammer being, by the arrangement, doubled.

The cranks are on discs which appear to have been intended for use as spur fly-wheels to drive other machinery, and one of the discs is provided with a heavy counterbalance. M.1809.

95. Model of a grinding machine. Watt Collection, 1876.

This appears to be a model of a machine intended for grinding or polishing metal articles. It has a horizontal shaft, carrying a lead-covered lap of mushroom shape. A wooden driving pulley is attached to the shaft, for receiving the requisite power from a gut band, and sliding bearings are provided, possibly for tightening this band. M.1796.

96. Wooden shaft. Watt Collection, 1876.

This is a vertical shaft with a horizontal cross arm on which is fixed a leaden weight and two similar masses in wood. It is said to have been used in some experiments on centrifugal governors. M.1819.

97. Valve and spindle. Watt Collection, 1876.

An ordinary mitre seated valve is shown, guided by its spindle. The free end of the spindle is provided with a universal joint connecting it with an iron rod. M.1822.

98. Model of a pump valve. Watt Collection, 1876.

This valve was probably intended for a mine pump, but the construction is not fully shown. The staple at the top is to enable the valve to be withdrawn from above by a simple hook. M.1817.

99. Model of a horse gear and crushing roll. Watt Collection, 1876.

This horse gear is in the form of a horizontal lever turning on a vertical axis. A projecting stud on the upper side of the lever forms a crank-pin from which a connecting rod is carried to a swinging lever. From this lever two links proceed to the axle of a vertical edge runner, which can be rolled in the fixed trough. The trough has a grid bottom through which the crushed material escapes when sufficiently reduced. M.1801.

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100. Heslop's beam engine. Presented by the Earl of Lonsdale, 1878. Plate II., No. 1.

This winding and pumping engine was erected about 1795, by Adam Heslop at Kell's Pit, Whitehaven, where it worked for many years ; it was subsequently used at other pits in the locality till its removal to South Kensington in 1878. Particulars of fourteen other engines of this type, erected in the district, are in existence, and it is known that many more were

built at Coalbrookdale (*see* drawings in adjacent frames and Structural Engineering Collection), where it is believed that the construction was first tried.

The arrangement, which is in reality a combination of a single-acting high pressure cylinder with a Newcomen engine, was patented in 1790 by Adam Heslop, although it appears to have been an infringement of Watt's patent for the separate condenser which remained in force till 1800.

There are two open-topped single-acting cylinders, one known as the "hot" cylinder, 34 in. diam. by 34 in. stroke, being near the connecting rod end of the beam, while the other, or "cold" cylinder, 25·5 in. diam. by 39 in. stroke, is at the other extremity, although in some cases both cylinders were at the same end. There is also an air-pump, 12·5 in. diam. by 17 in. stroke, but this was a later addition. The steam, which was supplied by a haystack boiler, on being admitted into the hot cylinder, raised the piston by its pressure; the return stroke was made by the momentum of the fly-wheel, assisted by the weight of the connecting rod and the action of the cold cylinder. The exhaust steam from the hot cylinder passed to the cold one by an eduction pipe, which, being immersed in cold water, acted as a condenser to the extent of "killing" or reducing the steam to atmospheric pressure before it entered the cold or Newcomen cylinder; here it was condensed by an internal jet, so that the atmosphere caused a down or working stroke of this piston. All of the valves were actuated by tappets on a plug rod, and any air was expelled from the cold cylinder by a snifting valve, which permitted a blow-through during the up stroke; this has, however, been displaced by the air pump. Pumping was done by a cast-iron beam 4 or 5 ft. above the main beam, and connected with it by links, as shown in an adjacent photograph. M.1464.

101. Drawing of Cartwright's engine. (Scale 1 : 8)

This arrangement, patented in 1797 by the Rev. Edmund Cartwright, D.D., was followed in the construction of several engines of the time. Although intended for steam, Cartwright pointed out that the engine might be worked by the vapour of "ardent spirit or ether."

A single-acting vertical steam cylinder is employed, having its piston-rod carried down to the bucket of the air-pump, which is placed below in an immersed condenser of the surface type formed by enclosing a cylindrical shell within another of larger diameter. The piston is forced downward by steam pressure until it nearly reaches the bottom of its stroke, when a spring on the crosshead closes the steam valve; the spindle of an exhaust valve in the piston afterwards strikes the cylinder bottom, and so permits the steam to escape into the condenser, thus allowing the piston to pass again to the top of the cylinder under the action of the fly-wheel.

The packing of the piston and its rod are stated to have been entirely of metal, and were early examples of metallic packing. M.2557.

102. Model of Cartwright's engine (working). (Scale 1 : 10.) Made in the Museum, 1902.

This model shows Cartwright's mechanism for converting the reciprocating motion of the piston into rotary motion. The engine itself presented several exceptional features (*see* No. 101), but the only other one of these followed in this model is that the valve motion is directly derived from that of the piston by a tappet action.

The arrangement for guiding the end of the piston-rod, in place of the then general parallel motion, comprised a long crosshead secured to the piston-rod and provided with two connecting rods coupled to two cranks geared together and revolving in opposite directions. In this way the oblique thrusts of the two connecting rods were caused to neutralise each other, and the piston-rod had only to resist the direct piston effort, which it was able to do without the assistance of a parallel motion or other form of guide.

This arrangement of mechanism was abandoned for many years, but it is now successfully employed for driving the two revolving prisms in the rotary form of air-pump known as a "pressure blower"; in such cases, however, the engine crosshead is also provided with slide guides, as shown in an attached illustration. M.3253.

103. Drawing of Fenton and Murray's engine. (Scale 1 : 8.)

This shows the self-contained or "portable" engine patented in 1802 by Matthew Murray for producing "circular power." Several engines of this type were constructed by Messrs. Fenton, Murray & Wood, of Leeds; the one represented was of 4 h.p., and was erected in 1802 for grinding bark at a Bermondsey tannery. The arrangement is exceptionally compact, owing to the shortness of the virtual connecting rod employed, its length being equal to one-half of the stroke only (*see* No. 104).

The engine has a vertical double-acting cylinder, with an air-pump and jet condenser in a tank below. The valves are of the drop type, and are driven by tappets on a revolving shaft connected with the crank-shaft by bevel wheels. M.2557.

104. Model of Murray's engine (working). (Scale 1 : 10). Made in the Museum, 1902.

This shows the mechanism adopted in the self-contained engine, patented in 1802 by Matthew Murray (*see* No. 103), for converting reciprocating motion of the piston into rotary motion of the shaft. It is an application of the fact, originally published in 1666 by De la Hire, that when a circle rolls within another of double its diameter, any point in the circumference of the rolling circle describes a straight line. Murray appears to have been the first to construct practically a machine embodying this method of obtaining a straight line, or "parallel" motion; he, moreover, fully describes a means of taking up the wear on the centre of the rolling wheel, by the use of adjustable double cones.

On the fly-wheel shaft is a crank pin having loose on it a spur wheel of equal radius to the crank path, while on the rim of the spur wheel is secured a crank pin to which the piston-rod is directly attached; the spur wheel engages with an internally geared rim of double its diameter rigidly secured to the engine framing. By these arrangements a guided straight line motion is obtained without the use of links or guides, while, owing to there being no extension of the piston-rod or anything beyond it, the engine is remarkably compact. Murray's mechanism possesses the further advantages of giving a true harmonic motion, and having all its parts revolving so that they can be directly balanced, while there is a total absence of oblique thrust. For these reasons it is, although now no longer used in steam engines, still extensively adopted for giving reciprocating motion to the tables of flat-bed printing machines as shown by a model in another room. M.3254.

105. Beam engine. Received 1907.

This form of "portable" or self-containing condensing beam engine was brought out in 1805 by Matthew Murray, of Leeds. It proved in practice to be not easily accessible, and only a few engines were, therefore, made. It is interesting, nevertheless, as having the same general arrangement as the side-lever engine which subsequently became the recognised type for marine purposes.

The engine is contained within a tank supported on four feet. A dividing partition enables the cylinder and valve box to be packed with non-conducting material, while the air-pump and condenser are surrounded by water. The cylinder crosshead has two side rods working on to a pin on the end of a beam rocking on a centre on the underside of the tank. The other end of the beam has a connecting rod to a crank-shaft above, with a large fly-wheel. The

air-pump is worked similarly by side rods from an intermediate point in the beam. Neither cylinder nor air-pump crossheads are guided. Steam is distributed to the cylinder by the "locomotive" slide-valve which had been patented by Murray in 1802. The valve has a rack on the back geared into by a sector which is actuated by a rod having a frame at the other end embracing a cam on the crank-shaft; the cam gives a period of rest at the end of each stroke. The injection cock to the condenser can be adjusted by a hand lever moving over an index plate.

The engines actually made were of 6 h.p.; the small example shown has a cylinder 3 in. diam. by 5 in. stroke. M.3517.

106. Model of grasshopper or half-beam engine (working). (Scale about 1 : 12.) Received 1869.

The grasshopper engine, so named from its peculiar motion, is intermediate between the older beam engine and the later direct-acting type; it has been known also as the half-beam engine. The effort of the piston-rod is transmitted directly to the crank in this example, and is not felt on the beam gudgeons, so that frictional loss is reduced.

The cylinder is vertical and its piston-rod is connected with a crosshead whence two connecting rods return to a double-throw crank-shaft below. The crosshead is fixed in one end of the beam, the other end being pivoted on two rocking links; the centre of the beam is constrained by two bridles, half the length of the beam, attached to the framing. A straight line motion is thus impressed on the crosshead. The air-pump is attached to the "parallel" point in an extra parallelogram obtained from the centre of the beam. A plunger and a bucket-pump are driven directly from the beam. Steam is distributed by a piston valve actuated by a countershaft which is driven by an eccentric on the crank-shaft. A Watt governor controls the throttle valve. The hand-wheels for controlling the engine are grouped on a platform. M.1174.

107. Models of table engines (working). (Scales 1 : 4 and 1 : 16.) Maudslay Collection, 1900. Plate II., No. 2.

The original form of this engine, as patented by Henry Maudslay in 1807, is represented by an adjacent drawing, from which these models differ only in detail. Many engines of this kind were made, and some are still in existence; till the Lambeth Works were closed in 1900, two of them were regularly engaged there in driving some of the machinery.

The cylinder is carried vertically on a cast-iron table, beneath which are the crank-shaft bearings and the condensing arrangements. The piston-rod passes through the top cover and terminates in a balancing or articulated crosshead carrying a pair of wheels which roll between guides formed in an independent framing secured to the table and the cylinder. From the crosshead there are two connecting rods, which proceed to two independent cranks in the crank-shaft below. The steam is distributed by a plug valve rocked by a rod connected with a triangular cam on the crank-shaft. The air, cold water, and feed pumps are worked by an inverted T-bob driven by a roller on the intermediate portion of the crank-shaft. M.3121.

108. Model of table engine (working.) (Scale 1 : 8.) Received 1892.

This represents a self-contained and compact form of vertical engine in which, moreover, a long connecting rod is used; the arrangement is, however, expensive to make and unsuited for high speeds, so that the inverted cylinder type of engine has practically supplanted it.

The cylinder is mounted on a cast-iron table, which is supported by four columns upon a base plate carrying the crank-shaft bearings. The piston-rod passes through the top cover of the cylinder, and its crosshead slides in

two pairs of guides cast with the cover. The connecting rod is in the form of a loop, or "kite," embracing the cylinder, but clearing it sufficiently in every position, and requires only a single crank in the shaft. The slide valve is worked by a similar "kite" rod from an eccentric which also drives the horizontal force pump for feeding the steam boiler. The speed is regulated by a simple centrifugal governor which controls a disc throttle valve in the steam pipe. M.2448.

109. Trevithick's high-pressure steam engine. Received 1879. Plate II., No. 3.

This early high-pressure engine and boiler were made by Richard Trevithick in 1811 at Hayle Foundry, Cornwall, for Sir Christopher Hawkins, Bart., of Trewithen, and were in constant use for thrashing, chaff-cutting, and similar work, until removed to South Kensington in 1879. It is stated that this was the first steam engine that drove a thrashing machine.

The boiler is of the Cornish type, 7 ft. long by 4·5 ft. diam., with a single internal flue 27in. diam.; beyond the fire bridge the circular shape is departed from, one side of the flue being flattened so that the section is 28 in. by 21 in. The products of combustion from the furnace flue were led by a "wheel draught" through external masonry flues to the chimney, the total heating surface so obtained being probably about 50 sq. ft. The shell of the boiler is shaped at the back to receive the steam cylinder, which is open-topped and placed in the boiler so as to be steam-jacketed. The safety-valve is weighted for a maximum pressure of 40 lb. above the atmosphere.

The cylinder is 9·5 in. diam. by 26 in. stroke, and the long connecting rod, which is attached directly to the piston, passes up to a crank on a fly-wheel shaft above. The fly-wheel is 10 ft. diam., with a grooved rim for a driving rope, and has cast on it a balance weight that assists the return stroke of the piston. Steam is distributed by a three-way cock which is rocked by a cam on the crank-shaft. The feed pump is worked by a lever from the piston. M.1470.

110. High-pressure engine, presented by the Rt. Hon. the Earl of Shrewsbury and Talbot, K.C.V.O., 1911. Plate II., No. 4.

This engine was employed for general purposes at a salt works at Ingestre near Stafford for upwards of half a century; it has been disused since 1882, when the works were closed down. It is said to have been removed thither from Brereton, near Rugeley, where it had been used in winding from a coal-pit. Nothing is known as to the maker of the engine, but it exhibits several features that were peculiar to the designs of Richard Trevithick, the pioneer in the adoption of high-pressure steam, some of whose engines are known to have been constructed at Bridgnorth about 1815. The engine is later than those (Nos. 109 and 351) shown near at hand, in that the cylinder is separated from the boiler and has an independent framing.

The engine is of the vertical, return connecting-rod type, with a cylinder 7 in. diam. by 24 in. stroke. Steam admission and exhaust are controlled by a four-way cock, the lever or spanner of which is struck by two tappets adjustable on a tappet rod hanging from the crosshead, in a similar way to that in Trevithick's road locomotive model (*see* No. 161). The tail of this spanner has a strap attached to limit its fall below the point where the tappet can again strike it. The area of both the steam and exhaust ports in the four-way cock is 1·25 sq. in. There was no governor, but there was a stop-cock on the steam pipe. The exhaust steam passes to a feed water heater of the form adopted by Trevithick in the high-pressure engine which he applied to a dredger in 1803; he foresaw the desirability of saving some of the heat rejected in the exhaust steam. The feed heater consists merely of a casing surrounding about 4 ft. of the feed pipe which passes through stuffing-boxes at either end. The casing is prevented from shifting by iron loops. (*N.B.—This feed heater, owing to exigencies of museum space, is shown about a foot further forward than*

its true position.) The plunger feed pump, 2·125 in. diam. by 5·5 in. stroke, is worked from a pin driven into the space between the boss of the pinion and the crank-shaft, on one end of the latter. Interesting details of early machine construction may be noted, such as the square cast-iron crank-shaft with its narrow bearings, bridles for holding cocks on their seats, and the method of staying the crosshead guides.

At Ingestre, steam at 35 lb. pressure was supplied by an egg-ended boiler, of more recent date than the engine, 8·5 ft. long by 3 ft. diam., set with a partial wheel draught. The engine is said to have developed 5 h.p., which would have meant a mean effective pressure of 25 lb., and the not improbable speed of 45 revs. per min. ; as a boiler of the size stated could evaporate sufficient steam for that power, it is no doubt correct. M.3949.

111. Model of diagonal oscillating engine (working). Maudslay Collection, 1900.

The double-cylinder diagonal engine with a single crank was designed and patented in 1822 by Sir M. I. Brunel, chiefly for use as a marine engine. The model shows the design as modified by the use of oscillating cylinders, and is believed to represent an engine built by Messrs. Maudslay, Sons and Field, for working the drainage pumps used during the construction of the Thames Tunnel, 1825–42.

The cylinders are each 0·77 in. diam. by 1·43 in. stroke, and incline upward, at 45 deg., to the single crank-shaft. Each cylinder is double-acting, and the steam distribution is performed through ports in one of the trunnions, which, by its oscillation, acts as a slide-valve. As Joseph Maudslay had in 1827 introduced a much more efficient valve-gear for this class of engine (*see* Marine Engineering Collection), the motor represented was probably made during the early stage of the tunnel works. M.3125.

112. Model of twin-cylinder engine. (Scale about 1 : 24.) Received 1911.

The twin-cylinder or "Siamese" engine, patented in 1839 by Mr. J. Maudslay and Mr. J. Field for marine purposes (*see* Marine Engineering Collection) was modified for land use in exceptional cases, as here shown ; the advantage of the arrangement is that a long stroke can be accommodated in a limited height, but mechanically it is undesirable, so that few were made; in common with the "table" (*see* No. 107) and other engines of this time it was superseded by the direct-acting type.

The two cylinders have a common crosshead, which is of a T shape, working in guides between the cylinders ; it is formed of two plates between which swings the connecting rod, whose point of attachment is at the tail of the T while its big end joins to the crankshaft overhead. The valve is a simple four-way cock, the lever of which is actuated by an eccentric. M.3901.

113. Diagram model of compound engine. (Scale 1 : 4.) Contributed by J. Warriner, Esq., 1857.

This design for a two-stage expansion engine was patented by Mr. J. Milner in 1853. The cylinders are side by side, with the valve chests between them, and the cranks at right angles. Reversal is effected by loose eccentrics, and a piston-valve which interchanges the exhaust and steam passages.

The steam is first admitted into the smaller cylinder and is cut off at half stroke; it is then led to the larger cylinder whose piston is at the commencement of its stroke. When the piston is at the end of its stroke, this steam will have been doing work while expanding to a volume equal to that of the low pressure cylinder and half the high pressure. This method of working causes, however, an exceptional temperature range in the high pressure cylinder. Inv. 1857–20.

114. Sectional model of three-cylinder engine. Presented by G. L. Fuller, Esq., 1893.

This three-cylinder engine was patented by Mr. Fuller in 1853. It would now be described as a two-stage expansion engine with one high pressure and two low pressure cylinders. The cranks are equally spaced at 120 deg., this arrangement being adopted with the intention of obtaining uniform turning moment.

In the model the central cylinder is the high pressure one; by using two low pressure cylinders a single cylinder of inconveniently large dimensions is avoided. Into the ports are fitted cylindrical plug-valves, by rotating which the distribution of the steam to the cylinders can be varied. To assist in following the action, the high pressure steam ports and spaces are coloured red and the low pressure black. M.2527.

115. Vertical engine (working). Maudslay Collection, 1900.

This single cylinder pedestal engine was made by Messrs. Maudslay, Sons and Field for driving their collection of models at the International Exhibition of 1862.

The cylinder is 4·1 in. diam. by 4·5 in. stroke, and is provided with a jacket through which the exhaust steam passes on its way to the condenser. The guides are cylindrical bars, and the main crankshaft bearings are carried by the pedestal. The steam is distributed by an ordinary slide-valve, driven by a single eccentric, which also works the feed pump. The condenser and hot-well are arranged in the base, within which is also a vertical air-pump driven by an additional crank in the crank-shaft. The speed is regulated by a belt-driven Watt governor, carried on the top of the cylinder casing and controlling the steam supply by a disc throttle-valve. The feed delivery pipe is fitted with a weighted relief valve, so that when the feed pipe of the boiler is closed the water pumped can return to the hot-well. M.3126.

116. Model of horizontal steam engine. (Scale 1 : 6.) Made by J. B. Jordan, Esq., 1865.

This form of high-pressure engine was designed by Mr. Jordan, and used in the Clunes Gold Mines, Australia, for driving stamps.

It has a cast-iron bed, supporting the cylinder and guides, together with two bearings of the crank-shaft. Two equal fly-wheels are provided and are intended to be used as travelling wheels in conveying the engine to its destination, a temporary forecarriage being arranged under the cylinder end for the journey. M.2762.

117. Model of Robertson's engine (working). (Scale 1 : 5.) Made in the Museum, 1909.

This sectional model represents one of two engines, 8 in. diam. by 10 in. stroke and of 8 h.p., which were used at the Royal Albert Hall from 1871 till 1909 to drive two ventilating fans. They were constructed by Mr. J. Robertson under his patent of 1868.

A connecting rod is dispensed with, as the cross-head actuates the crank disc directly by sliding through a ball socketed eccentrically within it. This mechanism gives to the piston-rod and piston a helical motion which is made use of to distribute the steam. To this end, the piston is made so much longer than the stroke as to keep always covered the central zone of the cylinder where the steam inlet and exhaust outlet pipes opposite one another are situated. The ports, necessarily of helical shape, are in the body of the piston and lead to annular openings on the top and bottom faces. The steam ports may be made of such a length as to cut off at about 0·1 of the stroke onwards; the piston is shown cutting off at 0·62 of the stroke. The piston is

packed with Ramsbottom rings at the two ends and with a longitudinal strip between the two steam ports.

The same principle has been applied also as a pump (*see* No. 632).

M.3710.

118. Safety steam motor. Lent by Messrs. Hathorn, Davey & Co., 1888.

This combined arrangement of boiler and condensing steam engine was patented by Mr. H. Davey in 1884 and introduced as a domestic motor, since owing to the boiler working at atmospheric pressure no explosion is possible through neglect or unskilled attendance.

The steam cylinder is double-acting, and is arranged vertically within the steam space of the boiler; the steam is distributed by a slide-valve driven by an eccentric on the crank-shaft, and the supply is controlled by a throttle-valve connected with a centrifugal governor.

The furnace, boiler, and surface condenser are all formed in one casting, and the firebox is crossed by a deep water pocket. The level of the water within the boiler is visible through a glass window in a feed box on the side, which contains a copper float that automatically admits water as required.

The surface condenser is provided with vertical tubes, with the cooling water, which may be stored in the containing casing or in a detached tank, circulating outside them; it is cleared by an air pump of the vertical plunger type driven by an overhanging crank-pin on the fly-wheel shaft. It is stated that the consumption of coke is about 6 lb. per h.p. per hour. M.1909.

119. Drawing of double-acting steam engine. Contributed by G. Cawley, Esq., 1895.

This shows a form of self-contained reciprocating engine introduced by Mr. Cawley.

The piston is of exceptional length, being two single-acting pistons cast together; the connecting member contains a transverse slot in which works a block encircling the crank-pin. The crank is of the bent type, and with the block, is got into position through the side of the cylinder by an opening that is closed by a cover which contains one of the crank-shaft bearings. Steam is distributed by a rotating slide-valve attached to the inner end of the crank-shaft. This example was designed to work suspended, and has its steam or compressed air supplied through a flexible pipe. M.2750.

120. Diagram model of double-cylinder engine. Presented by the Institution of Civil Engineers, 1868.

This illustrates a type of engine in which dead centres are avoided although only one crank is employed. The device was patented in 1839 by Elijah Galloway, but was not practically used until considerably later (*see* Nos. 121 and 122). Two vertical simple cylinders are placed side by side, with the crank-shaft between them, and the piston-rods are connected by return links with the ends of the base of a triangular frame, the apex of which embraces the crank-pin, while the middle point of the base is constrained to move in a vertical line. M.1086.

121. Drawings of double-cylinder engines. (Scale 1 : 24.) Presented by J. Bernays, Esq., 1906.

This compact form of engine (*see* No. 120) was re-invented by Mr. Bernays in 1874 with a simple and efficient valve gear, but built only to a limited extent; it has, however, since been used for both stationary and marine engines (*see* No. 122).

The arrangement consists of two vertical cylinders, which may be compounded, placed side by side with the crank-shaft above or between them. The piston-rod ends are connected by links with the ends of the base of a triangular frame, the apex of which embraces the crank pin, while the middle point of the base is guided in a straight line. The valve gear consists of a single eccentric, the strap of which has two connecting pins forming the corners of the base of a similar triangle which is controlled in the same way as the other triangle; each of the pins drives one valve.

One of the designs shown is for a compound mill engine having cylinders 30 in. and 45 in. diam. by 50 in. stroke, to indicate 500 h.p. at 45 rev. per min. with a steam pressure of 50 lb. per sq. in. It has a Meyer expansion valve on the high-pressure cylinder, and the air-pump is driven by a lever from the middle of the triangle base. The other design represents a blowing engine having two steam cylinders 30 in. diam. and two air cylinders 72 in. diam., the common stroke being 70 in. The air cylinders are placed vertically below the steam cylinders and there is very little framework. In both designs cross-head guides are dispensed with on account of the small obliquity of the connecting-rod links. M.3443.

122. Double-cylinder engine (working). Made by Messrs. John Musgrave and Sons, Ltd., 1893.

This is a small example of an engine differing only slightly from the preceding (Nos. 120 and 121).

Two cylinders, arranged side by side, have a common connecting-rod in the form of a triangle, the apex of which encloses the pin of the overhanging crank. The two other corners of the triangle are, by very short links, connected respectively with the two piston-rods, the cross-heads of which slide in ordinary guides. From the middle of the top of the triangle two bridle rods couple the connecting-rod to a stationary centre on the side of the framing, and so restrict the movement and close the chain. The valves are in the form of cylindrical slides, and receive their motion from a common eccentric.

The example has 3 in. cylinders, with 4 in. stroke, and is intended to run at 300 rev. per min., when it will indicate about 3 h.p. M.2532.

123. Double-cylinder diagonal engine (working). Lent by R. Laybourne, Esq., 1896.

This represents an arrangement of engine patented by Mr. Laybourne in 1879. There are two diagonal cylinders acting on a single overhanging crank-pin; the guides for the crossheads are formed on the front covers of the cylinders. The slide-valves are driven by a single pin, projecting from a block that is fixed in a slot formed on a return crank keyed to the crank-pin. When the block is at one extremity of the slot the valves work as in forward gear, while when at the other extremity they secure backward running. The block is moved in its slot for reversing by worm and pinion gear, engaging in a rack fixed in the slot; this gear is adjusted by a small hand-wheel which, if held while the engine is running, brings the valves into mid-gear, and then when rotated moves them into the desired position. M.2957.

124. Three-cylinder engine (working). Lent by P. Brotherhood, Esq., 1888.

This type of steam engine is designed for conditions requiring a high speed and great compactness in the mechanism, and is largely used for driving dynamos and fans, also the propellers of the Whitehead torpedo—in this latter case using compressed air.

The three cylinders are single-acting and arranged at 120 deg. round the crank-shaft. The connecting rods, which work on a common crank-pin, have spherical small ends, upon which fit pistons fitted with metallic packing,

there being no piston-rods. The cylinders being single-acting, there is no reversal of stress in the connecting rods, so that slackness in the connecting-rod brasses does not cause a heavy knock, as would be the case in a double-acting engine—a circumstance which is conducive to quiet working at high speeds. The crank chamber is closed and retains a quantity of lubricant—an arrangement which prevents the dust and grit from getting into the working parts, and also economises oil. The crank is of the overhanging type, with a counterbalance weight, and the pin drives a small crank arm connected with the valve gear. Steam is distributed to the cylinders by three piston-valves driven by a crank-pin, the valve motion for each cylinder being equivalent to that in an ordinary engine.

The governor, which is beyond the valve gear and enclosed in a removable cover, controls a small throttle valve of the piston type, and is loaded by a spring, which can be adjusted by an external hand wheel, so that the speed of the engine can be varied while running.

This example has cylinders 3 in. diam. by 4 in. stroke, and indicates 5 h.p. when running at 600 rev. per min. It is shown driven by power, with some of the covers removed so as to render the internal construction visible.

M.1924.

125. Model of horizontal engine. (Scale 1 : 3.) Lent by Killingworth W. Hedges, Esq., 1913.

This model represents current practice in 1869 in horizontal engine construction by Messrs. Easton and Amos. It has a box girder bed with the cylinder and crankshaft brackets bolted to it. There are two guide bars in the vertical axial plane, the connecting rod having a long forked small end. The speed is controlled by a Porter governor (*see* No. 299). M.4233.

126. Model of horizontal steam engine (working). (Scale 1 : 4.) Lent by Messrs. R. Hornsby and Sons, 1885.

This represents a high pressure engine, with a steam-jacketed cylinder supported throughout its length on a cast-iron bed. The guides are cast with the bed and bored out, the crank-pin is attached to an overhanging crank-plate, and the outer end of the crank-shaft is carried by an independent bearing. The engine is fitted with a governor gear that automatically adjusts the degree of expansion to the work being done. On the crank-shaft are three eccentrics, but one of these is solely used for working the feed pump. The others drive the main slide-valve and the "back cut-off" or expansion valve. The travel of the expansion-valve is determined by the position of a block in a rocking link, and this position is adjusted by the governor. When the governor rises it rotates the sheave of a small eccentric connected with it, and by this means moves the block along the link; as an eccentric is a non-reversible means of transmitting motion it is here introduced to prevent pressure from the link interfering with the action of the governor. The cylinder is 12·25 in. diam., by 22 in. stroke; when the engine is supplied with steam at 60 lb. pressure and is making 95 rev. per min., it indicates 50 h.p.; the same design was followed for engines with cylinders up to 22 in. diam. by 40 in. stroke indicating 185 h.p. M.1625.

127. Armington-Sims engine. Made by Messrs. Greenwood and Batley, 1889.

This is an example of a high-speed horizontal engine of American design. The cylinder, which is 5 in. diam. by 7 in. stroke, is overhung and is finished externally by polished metal lagging covering the flanges as well as the usual non-conducting felt. The crank is formed with two counterbalanced discs, and there are also two fly-wheels, while the crank-shaft has exceptionally long bearings; the crank race is, moreover, enclosed by a cast-iron box, which

retains any oil thrown off, and also carries the crank-pin lubricator, these various arrangements being resorted to on account of the high speed employed. The slide-valve is of the piston type, with the steam space in the middle, as was usual in the early long D valves; it is driven, through a rocking shaft, by an eccentric of variable throw within one of the fly-wheels. The governor, which is arranged within this fly-wheel, consists of two heavy swinging levers pinned to opposite arms of the fly-wheel, and pulled inward by helical springs. When the levers swing outward, through centrifugal action, they turn the main eccentric and also an eccentric carrying it, moving them in opposite directions, so that the main eccentric is shifted along an approximately straight line, the cut-off being thereby altered while the lead remains nearly constant. M.2261.

128. Model of engine with "Corliss" valve gear (working). (Scale 1 : 6.) Made by Messrs. T. and C. J. Coates, from drawings supplied by Messrs. John Musgrave and Sons, Ltd., 1898. Plate II., No. 5.

The horizontal engine represented was made by Messrs. Musgrave for driving a jute mill in Calcutta; its cylinder is 19 in. diam. by 36 in. stroke, and the fly-wheel, which is 12 ft. in diam., weighs 5·75 tons. The power is transmitted from the fly-wheel by eleven ropes 1·25 in. diam., which drive the line shafting of the various floors of the factory. The crank-shaft neck is 7·5 in. diam. by 15 in. long, and its bearing is composed of four brasses which can be separately adjusted; the outer bearing of this shaft is, however, of the simple two-piece type. When supplied with steam at 80 lb. pressure and running at 80 rev. per min., the engine indicates 120 h.p.; if fitted with a condenser such an engine would economically exert 140 h.p.

The valve gear is of the "Corliss" type, and under the control of the governor; it alters the degree of expansion to meet the variations in the load, without the intervention of any throttle valve, and as usually set the speed does not vary more than 2·5 per cent. from no load to full load. The adjacent diagram shows how the point of "cut-off" changes with the slight alteration in the governor speeds.

The original Corliss valve gear was invented in 1849 by Mr. G. H. Corliss; not being an engineer he experienced exceptional difficulty in getting his invention tried, but the results obtained with it ultimately led to its very extensive adoption; the first Corliss engine in Europe was that shown at the Paris Exhibition in 1867. The leading features of the arrangement are: the employment of separate steam and exhaust valves at each end of the cylinder, so that any alteration of the point at which steam is cut off can be made without interfering with the action of the exhaust valves; the valves are cylindrical, and each is capable of being separately adjusted. The two exhaust valves, which are at the bottom of the cylinder, are rocked by a single eccentric, while the two steam valves at the top are rocked by another eccentric. The steam eccentric swings an arm provided with a cylindrical end, upon which are two hardened steel plates; as the arm swings, these plates engage with similar plates attached to flat levers that proceed from cranks on the spindles of the two steam valves. As the arm reciprocates, the steam valves are alternately opened, but, at certain points, determined by the speed of the governor, the lever of the steam valve then opening slips off the corresponding driving plate; the valve then left free is rapidly turned into a closed position by the action of a helical spring, The spring is contained in a small cylinder provided with two air "dash-pots" by which the quick closing motion is quietly arrested; this sharp and automatically adjusted cut-off is now to be found in all modern "trip" gears.

The governor shown is of the high speed loaded type, and has its sensitiveness adjustable by means of a spring which is contained within the central weight; it is driven by three cotton ropes, but further to reduce the risk of the engine running away, through the governor stopping, an independent gear is fitted, so that if, after the engine has been started, the speed of the governor falls below a certain limit, a trigger releases a weighted lever which automatically stops the engine through its valve gear. M.3015.

129. Model of horizontal tandem compound engine (working). (Scale 1 : 12.) Made by Adam Gilbert, Esq. Received 1910.

This represents a very common type of compound condensing mill engine having the two cylinders arranged in line and the piston rods driving a single overhung crank. The cylinders are mounted on one bed-plate, and the front cylinder is connected with the main crank-shaft bearing by a girder frame in which the bored crosshead guides are formed. The shaft carries a grooved fly-wheel; a crank disc is fixed to its front end and its rear end is supported on a separate pedestal bearing.

The high-pressure cylinder is fitted with double-beat inlet valves actuated by the variable expansion trip gear patented by Dr. W. R. Proell in 1881. In this arrangement, a horizontal lever, oscillated by an eccentric, has suspended at each end a bell-crank lever; the vertical arms of the bell-cranks have notches at their lower ends, which, in their downward motion, catch upon and depress the ends of short pivoted levers which are connected with the valve spindles. The motion of the rocking lever brings the horizontal arms of the bell-cranks periodically into contact with a horizontal plate, the position of which is controlled by the governor; this causes the notches to slip off the valve levers and allows the valves to close sharply under the action of springs and dash-pots mounted above them. If the speed increases the plate will rise and the valves will close earlier in the stroke. The exhaust valves are of the "Corliss" type (*see* No. 128). The low-pressure cylinder has Corliss inlet and exhaust valves, and the inlet valves have a hand adjusted trip gear of the modified "Reynolds" type. A wrist plate, loose on the valve spindle, carries a spring catch, which engages with an arm on the valve spindle; the wrist plate is oscillated by an eccentric and, at a certain point of the motion, the catch is disengaged from the valve arm by a fixed roller, so releasing the valve, which closes under the action of a spring and dash-pot. The positions of the releasing rollers are adjusted by hand. One eccentric serves for all the inlet valves and another for the exhaust valves. A Porter governor, provided with a dash-pot for damping out sudden and violent fluctuations, is fitted. The steam pipe between the cylinders forms a receiver, and both cylinders and pipes are lagged with wood.

The cylinders are 12 in. and 21 in. diam. by 30 in. stroke; when the engine is supplied with steam at 100 lb. pressure, and is making 110 rev. per min., it develops 136 effective h.p., with economy, or a maximum of 186 indicated h.p. The fly-wheel is 10 ft. diam. and is grooved for five ropes of 1·75 in. diam.

The engine is fitted with a jet condenser placed below the floor level, the air and feed pumps being placed beside it and driven by an "L" lever from the tail rod of the low-pressure cylinder. M.3807.

130. Model of vertical engine with Hackworth's valve gear (working). (Scale 1 : 6.) Made by Messrs. T. and C. J. Coates, from drawings supplied by the Brush Electrical Engineering Co., and Messrs. R. and W. Hawthorn, Leslie & Co., 1898. Plate III., No. 1.

In its general arrangements and details this model represents one of the two-stage expansion engines supplied by the Brush Co. to the City Road electric light station. The cylinders are 13·25 in. and 23·5 in. diam. respectively, by 13·5 in. stroke, and are both steam jacketed. When supplied with steam at 100 lb. pressure and delivering into a surface condenser the engine indicates 300 h.p. at 240 rev. per min. The fly-wheel is 7·5 ft. effective diam. and has 10 grooves for 1·25 in. diam. rope, by which a dynamo is driven.

The model deviates from the actual engine in that it does not show the second valve chest to the high-pressure cylinder, the valve of which is driven by an eccentric on the crank-shaft controlled by a governor contained within

a small fly-wheel. The high-pressure slide valves are of the double ported piston type, while the low-pressure valve is of the D-slide class; all have vertical balance cylinders above them. The exhaust valve of the high-pressure cylinder and the single valve of the low-pressure are actuated by the arrangement of valve gear shown on the low-pressure portion of the model.

Both of the valve motions represented were patented in 1859 by Mr. J. W. Hackworth, of Darlington; the details of that on the high-pressure cylinder were arranged by Mr. F. C. Marshall, while those of the low-pressure were devised by Mr. J. S. Raworth for an adjustable expansion arrangement only, reversal on electric lighting engines not being required. The Hackworth expansion and reversing gear consists of a single eccentric fixed to the shaft and opposite to the crank arm, from which the eccentric-rod proceeds in a direction approximately at right angles to the piston-rod. The end of the eccentric-rod is caused to move in a straight path, but one of adjustable inclination, while the valve-rod is attached to an intermediate point in the eccentric-rod. The motion directly derived from the eccentric gives the lead, which is constant, while that resulting from the sliding motion of the block in the inclined guide determines the cut-off and also the direction of running. M.3039.

131. Sectional models of high-speed engine and dynamo (working). (Scale 1 : 4.) Received 1901. Plate III., No. 2.

This type of engine was patented by Mr. P. W. Willans in 1884; with subsequent modifications it was extensively adopted for the direct driving of dynamos. The engine is of the single-acting, two-stage expansion type with two high-pressure cylinders and two low-pressure ones, arranged with the high-pressures above, and all acting on a two-throw crank-shaft with the cranks 180 deg. apart.

The guide or crosshead for the small end of each connecting rod is in the form of a trunk, working in a closed cylinder that acts as an air cushion: by this arrangement, combined with single-acting cylinders, the pressures on the brasses of the crank pins and shaft are never reversed, so that slack bearings are permissible without any knock resulting, to which feature the high working speed found practicable is chiefly due.

The steam distribution to each pair of tandem cylinders is effected by a long piston valve, extending through a trunk which serves as the piston-rod of the two pistons whilst also acting internally as a valve by its passage through the metallic glands at the cylinder end; as the valve face is travelling with the piston, Mr. Willans in his patent of 1885 overcame the difficulty of steam distribution by forming his eccentric on the crank pin. The details of the arrangement of the valve gear and connecting-rods of this class of engine are shown more fully in the sectional motion diagram (*see* No 288), since in the actual engine the whole of the crank chamber is completely enclosed, to retain the oil which forms a bath at the lower portion of this space.

The speed is regulated by a spring-loaded centrifugal governor, fixed on the outer end of the crank-shaft and adjustable by hand even while running. This governor moves an equilibrium piston-valve which controls the admission of steam, but before reaching it the steam has to pass through a separator which removes priming water and any solid impurities. M.3205.

132. Sectional model of high-speed engine (working). Received 1902.

This represents a single acting, inverted, two-stage expansion engine for directly driving a large fan for mine ventilation (*see* No. 677), or other purposes. The engine was patented by Mr. N. Chandler in 1886–8, and subsequently improved; the two cylinders are arranged tandem fashion, with the high pressure above, so that there is a single piston-rod acting downward

upon a crank-shaft below, while the steam distribution is performed by two piston-valves similarly arranged and driven by a single eccentric. The cylinders are carried on a frame which contains guides for the piston and valve-rods, and the bearings for the crank-shaft; it also forms a closed chamber in which the oil is retained and distributed over the bearings by the motion of the revolving parts, access to it being, however, obtainable by side doors.

A special feature of this engine is the construction of the "sleeve" at the lower end of the valve, by which, while permitting the passage of the exhaust steam through itself, the valve can close the exhaust port, thus giving compression at the end of the stroke so as to absorb quietly the momentum of the moving parts and assist them on their return stroke. The action of the steam in the engine is as follows:—Boiler steam is admitted above the high-pressure piston, which then makes a down stroke; in the next up stroke this steam is allowed to pass to the under side of the high-pressure piston and into a receiver, from which, in the next down stroke, it is admitted to the top side of the low-pressure piston; from this, at about the completion of this down stroke, it is discharged into the exhaust pipe, or condenser, with which the lower side of the piston is in communication, except when the cushioning at the end of the stroke is taking place. M.3262.

Rotary Engines.

133. Drawing of Watt's rotary engine, with condenser. (Scale 1 : 16.)

This is copied from the 1782 patent specification of James Watt, but there is no evidence that he ever constructed such an engine. The drawing shows a piston in the form of a closely-fitting radial arm projecting from an axial shaft in a cylinder. An abutment, arranged as a flap is hinged near a recess in the side of the cylinder, and swings while remaining in contact with the piston. Steam is admitted to the chamber on one side of the flap, and so causes an unbalanced pressure upon the radial arm.

The arrangement has been re-invented several times, and has been worked out in a practical form (*see* No. 135). M.2557.

134. Models of rotary engines. Maudslay Collection, 1900.

These wooden models represent the rotary engine patented by Joseph Maudslay in 1852; the same thing had, however, been patented by John Trotter in 1805.

The engine consists essentially of a rotating cylindrical chamber, within which rotates a smaller cylindrical chamber placed eccentrically so as to touch the first. The inner chamber has a slot at one point, through which projects a radial partition fixed to the outer chamber; the crescent-shaped space between the two chambers is thus divided into two parts, one of which is expanding while the other is contracting, as the chambers revolve. Steam being admitted through a port in the outer chamber causes an unbalanced pressure upon the partition, the opposite side of which is connected with the exhaust by a port in the inner chamber, and so drives the chambers round.

One model has the two chambers surrounded by a concentric casing to which the steam is admitted, the exhaust being through the axis. The other model is double and has three concentric rings with radial partitions between them, forming two chambers in which two eccentric rings rotate; no steam ports are shown on this model. M.3120.

135. Model of rotary engine (working). Presented by W. Routledge, Esq., 1869.

This is a model of a simple form of rotary engine made and patented in 1818 by Joshua Routledge, whose name is well known in connection with the engineers' slide rule.

The piston revolves on a shaft passing through the centre of the cylinder casing. The flap or valve hinged to the casing, with its free end resting upon the piston, acts like the bottom of an ordinary engine cylinder. The steam inlet port is on one side of the hinge, and the exhaust port on the other. The admission of steam is controlled by a slide valve, actuated by an eccentric on the fly-wheel shaft, so that the engine could work expansively, and the steam pressure resisting the lifting of the flap would also be greatly reduced, so diminishing the knock at this point, which, however, would always be a serious cause of trouble. The exhaust steam passes down to a jet condenser, provided with a supply of water from a containing tank, from which the injection is admitted through a regulating valve. The air pump which draws the air and water from the condenser and discharges them through a pipe passing out at the end of the tank, is a rotary machine constructed like the engine driven by spur gearing from the fly-wheel shaft. Some efforts to prevent leakage have been made by forming grooves in the side of the revolving piston and filling them with soft packing. M.3907.

136. Model of a rotary engine (working). Presented by the Rev. Patrick Bell, LL.D., 1868.

This engine shows one of the early attemps to obtain rotary motion from the pressure of steam without the intervention of a crank and connecting-rod; almost the same arrangement was proposed in 1838 by Lord Armstrong as a water motor, and an example subsequently constructed gave off 5 h.p. at 30 rev. per min., with an efficiency of 95 per cent.

A metal disc is secured to a horizontal axis carried in bearings, and the lower half of the disc is enclosed by a chamber of circular section having its axis a semi-circle. One end of this chamber is closed and provided with a pipe through which steam enters, the exhaust taking place through the open end. The disc is provided with three holes, each fitted with a circular plate turning on an axis radial to the disc, and these plates when set at right angles to the disc become pistons in the lower enclosing chamber. Toothed gearing is arranged to rotate these pistons into the plane of the disc on leaving the cylinder and back again immediately after entering, locking levers retaining them in position during the intervals. The steam pressure upon these pistons forces the disc round, but the engine is non-expansive, and although some provision for packing has been made, the leakage must have been considerable and the wear and tear excessive. M.1097.

137. Model of a disc engine (working). Presented by R. B. Prosser, Esq., 1893.

The disc engine was patented by Messrs. E. and J. Dakeyne in 1830, and subsequently improved by Messrs. W. Taylor and H. Davies besides others. In 1841 Messrs. Ransomes and Sims showed at Liverpool a Davies rotary engine of 5 h.p., the first portable engine on wheels. It drove a thrashing machine and was rendered self-propelling by pitch chains from the crankshaft to the travelling axle. A similar engine was applied with some success by Messrs. G. and J. Rennie to drive a screw propeller (*see* Marine Engineering Collection); more recently the arrangement has been extensively used as a water meter (*see* Nos. 510 and 511).

The chamber, which acts as a cylinder, is enclosed laterally by a spherical zone and endwise by a pair of cones whose apexes come together. The piston is a circular disc fitting the interior of the zone round its edge, and having at its centre a ball which forms the joint on which it gyrates. From the ball, and perpendicular to the disc, projects a rod whose further end is socketed in a crank arm attached to the shaft to be driven. There is a fixed radial partition in the cylinder, and a corresponding slot in the disc permits of the requisite motion. The disc and partition divide the chamber into four spaces, two of which are expanding while the other two are contracting; steam is admitted into the former and discharged from the latter

by ports formed through the spherical wall of the chamber, one on each side of the partition, and the disc itself, by its motion over them, performs the function of a valve. The engine may be reversed by interchanging the inlet and exhaust passages. M.2521.

138. Model of rotary engine. Presented by John Hick, Esq., 1887. Model of the same (working). Made in the Museum, 1895.

This simple form of rotary engine was patented by Mr. Hick in 1843.

A cylindrical drum revolves within a fixed cylindrical casing of considerably larger diameter. The drum is placed eccentrically within the casing so that the circumference of the revolving drum is in contact with the inside of the casing at one place. At one side of this line of contact is the port or passage for the admission of steam, and at the other side of it is the exhaust port. The circumference of the drum is divided longitudinally by two slots, fitted with cylindrical packings, through which two flaps or blades extend radially to the circumference of the casing. The inner ends of the blades are free to turn on a stud fixed centrally with the casing, and the exposed surface of these blades between the drum and the casing form pistons upon which the steam acts, and so causes them to revolve and carry round the drum. M.1840.

139. Tower's rotary engine with working model. Lent by Messrs. Heenan and Froude, 1889.

A complete 6 in. engine, together with a wooden model, are shown, which illustrate the mode of action of the engine patented by Mr. Beauchamp Tower in 1879, and now known as the "spherical" engine because the working chamber is a complete sphere.

The mechanism is equivalent to a universal joint connecting two shafts inclined together at an angle of 135 deg. The cross-piece of the joint is filled in so as to form a circular piston, and the jaws or bows of the joint are filled in solid to the shape of a quarter of a sphere. The whole joint is enclosed in a spherical chamber, and it will be seen that the disc alternately approaches and recedes from the spherical segments to which it is attached, as the shafts rotate. Throughout each revolution there are two cavities simultaneously opening, and two closing—all four varying at the same mean rate, so that if steam is admitted into the enlarging cavities, and be permitted to exhaust from those that are closing, continuous rotation of the shafts is obtained. The rotation of the segments upon the surface of the sphere is utilised to distribute the steam—ports in the spherical surface being uncovered at the correct intervals by the moving segments.

The chambers obtained in this engine are each equal to a quarter of the volume of the sphere, and in one revolution the total volume passed is equal to that of the sphere. As the only reciprocation is that due to the swing of the disc, the engine is suited for high speeds, and, for the power given off, is very compact. M.2281.

140. Rotary engine (working). Lent by Messrs. Fielding and Platt, 1888.

The action of this engine, patented in 1885 by Mr. J. Fielding, depends upon the oscillating motion which the cross of a universal joint has relative to the containing jaws when the system is rotated.

Two shafts are set at an angle of 165 deg. to each other and connected by a Hooke's joint; one serves as a pivot, the power being taken from the other. Four curved pistons are arranged on the cross-piece, two pointing towards one shaft and two towards the other, and on each shaft or jaw are

formed two curved steam cylinders in which the curved pistons work. The steam enters and leaves the base of each cylinder through ports in the shaft, which forms a cylindrical valve working in the bearing as a seating.

On the revolution of the shafts the pistons reciprocate in their cylinders in much the same way as in an ordinary engine, and the valve arrangement is such that while each piston is receding from its cylinder the steam pressure is driving it, and during the in-stroke of each, its cylinder is in communication with the exhaust. There are thus four single-acting cylinders making each a double stroke for one revolution of the driving-shaft. The engine has no dead centres, and has been run at 1,000 rev. per min. M.1911.

141. Rigg's revolving engine (working). Received 1892.

This machine, patented in 1885 by Mr. A. Rigg, will be found to resemble in its movements an oscillating cylinder engine held by its crank-shaft, and performing its cycle by the revolution of the framing round the crank-shaft, and the cylinder round the crank-pin. The varying chamber of a reciprocating engine is thus obtained, while the inertia stresses due to the reciprocating parts are almost eliminated.

The engine has three single-acting cylinders, the long plunger pistons of which act outwardly upon three crank-pins, projecting from the face of an overhanging fly-wheel. The closed end of each cylinder is formed into an eye, and fits upon a stud or trunnion fixed to the engine-bed. This stud is not on the same centre-line as the fly-wheel shaft, so that in a complete revolution each piston makes a double stroke, of a length equal to twice this eccentricity. By carrying the stud on a sliding block so that the eccentricity can be varied, the stroke of the engine is rendered adjustable. The engine is reversed by sliding the stud into line with the fly-wheel shaft and continuing the sliding so as to give the eccentricity on the opposite side. The passage of the working fluid to and from the cylinders takes place through the faces of the eyes at the cylinder ends, which are provided with ports. The fluid enters and leaves the engine by the block carrying the stationary stud, the face of the block forming a surface on which the nearest cylinder end revolves, and acting as a disc slide valve for the three cylinders. An adjacent sectional drawing shows clearly the details of this arrangement.

The engine can be worked by steam, air, or water, but the full advantage resulting from the variable stroke is only obtained when working with water, owing to the cylinder clearance increasing as the stroke is reduced. The ordinary speed of these engines is from 100 to 500 rev. per min. with water pressure of 750 lb. per sq. in. When steam or compressed air is used, as many as 2,000 rev. per min. have been obtained. M.2441.

142. Rotary engine (working). Made by the British Cycloidal Engine Syndicate, Ltd. Received 1911.

This is a rotary steam engine of the form patented by Mr. J. F. Cooley in 1901, 1903, and 1907. Its construction depends upon the fact that if two elements rotate in the same direction, about fixed centres, with a speed ratio of 3 : 2, then three points on the slower element, equidistant from its centre, will describe, relative to the faster element, one and the same two-lobed peritrochoidal curve known as a nephroid. If a piston of this form is made to revolve at the correct speed, in a suitably shaped revolving chamber, having the three describing points on it in contact with the piston, then the chamber will be divided into three expanding and contracting spaces which can be used as working cylinders.

In the engine shown, the piston is mounted on a horizontal shaft and placed eccentrically inside a closed cylinder having a trefoil-shaped interior section with packing strips placed at the describing points. These strips, which have swivelling heads with two lines of contact, are the only parts in contact with the curved surface of the piston; they are held in contact by

springs and have sufficient radial motion to render extreme accuracy of the piston form unnecessary. There are also other packing strips fitted in the cylinder ends and bearing against the flat ends of the piston. Pinions with 24 teeth are fitted to the shaft on each side of the piston, and these gear with internally toothed rings with 36 teeth fitted into holes in the cylinder ends through which the shaft passes. Both cylinder and piston shaft run in roller bearings mounted in the end covers of an outer casing that surrounds the cylinder, and a ball thrust bearing is fitted to the tail end of the shaft. The cylinder has three longitudinal ports cut through it leading to the interior working spaces, and the casing, in which the inlet and exhaust passages are formed, fits closely round it. These passages are separated by pairs of adjustable packing strips, fitted in slots in the casing and bearing against the cylinder, and an intermediate strip provides for a period of expansion. The cylinder in its rotation thus acts as a valve, admitting, cutting-off and exhausting the steam as the ports pass the packing strips. The cylinder ends are made steam tight in the casing by cast-iron rings rotating with it and fitting between two non-rotating gunmetal rings, the outer one of which is adjusted by set-screws passing through the casing cover and pressing on a cast-iron backing ring. The longitudinal packings are pressed inward by springs and adjusted by external nuts. The bearings have short steel rollers of large diameter which are prevented from winding by closely-fitting side plates; the rollers run on hardened steel rings. Such engines could be made to reverse by providing the casing with two sets of inlet and exhaust ports, and suitable valves for bringing either set into use.

This example has a steam inlet of 1·19 in. diam., and a piston 6 in. long; it was designed to develop 20 to 30 h.p. M.3844.

Steam Turbines.

143. Parsons steam turbine and high speed dynamo. Lent by the Hon. Sir Charles A. Parsons, K.C.B., F.R.S., 1890. Plate III., No. 3.

This is the original Parsons steam turbine, made in 1884. It worked for several years at 18,000 rev. per min., driving the dynamo which gave off 5 electrical h.p.

The motor consists of a series of parallel-flow turbines on the same shaft, the exhaust from the first being the supply for the second, and so on. By this arrangement the necessary velocity requisite for the efficient action of a steam turbine is greatly reduced. To allow for the increased volume of the steam as its pressure falls in passing through the machines, the proportions of the turbines alter as the final one is approached, the passages being enlarged and the pitch of the blades increased. A set of guide blades, with its corresponding rotating ring, forming one element of a later turbine, is shown separately beside the machine. End thrust is obviated by employing two equal series of turbines on the same spindle on each side of the central steam inlet, the exhaust taking place from each end equally. By this arrangement also, glands are avoided as the slight leakage through the bearings under the exhaust pressure is easily collected and occasions no loss. To prevent vibration the bearings throughout are not quite rigidly fixed to the main castings, but are permitted a slight movement between clamping washers, the alternate washers fitting the casting and clearing the outside of the bearing, and *vice versa*. The lubrication of the bearings is effected by a current of oil continually circulated by a small screw pump formed on the main shaft. In its course the oil passes through the hollow shaft of the dynamo so that it shall assist in cooling the armature and commutator.

The governing is performed by a cylindrical throttle valve actuated by a leather diaphragm, on one side of which the air pressure is reduced by a kind of fan attached to the main shaft. The exhausting action of the fan is partially neutralised by air entering through a pipe which leads from the

top of the field magnet of the dynamo, where an iron arm turning on a vertical axis is, by the attraction of the field magnet, drawn round, against the action of a spring, into a position that causes its extremity nearly to close the entrance to the air-pipe. By this arrangement the opening of the throttle valve is regulated by the centrifugal action of the fan and by the intensity of the magnetic field, the control being partly mechanical and partly electrical.

The dynamo has a drum armature, but, owing to the high speed employed, only a few convolutions are required, which, being of large section, give a very low internal resistance. The commutator is built up of short gun-metal segments insulated with asbestos and dove-tailed into steel rings. The machine is shunt wound. M.2319.

144. De Laval's steam turbine. Received 1896. Plate III., No. 4.

This remarkable steam engine, invented and developed by Dr. C. Gustav P. de Laval, owes its success to the discovery by him, in 1889, of the fact that the velocity of the particles of an escaping jet of steam is increased by discharging through an expanding orifice, the conversion of the energy of the steam into momentum being so complete that, when applied to a form of Pelton wheel or impulse turbine (*see* No. 13), a high efficiency is obtained. Without the expanding orifice, a simple steam jet turbine is one of the earliest forms of steam engine (*see* No. 33), and very uneconomical, but by the use of many such turbines in series an efficient engine is also obtained (*see* No. 143).

In the De Laval turbine, shown in section, the revolving wheel is built up of separate vanes that are clamped by side discs in a way that resists the severe centrifugal stress resulting from the immense velocity required, while at the same permitting of well-finished and correctly shaped vanes being employed. The steam is directed, at an angle of 19 deg. with the plane of the wheel upon one side of it, through the expanding jet orifice, and after gliding round the concave faces of the vanes leaves the opposite face of the wheel with scarcely any dynamic energy remaining in it. The wheel is enclosed in a casing that communicates with the atmosphere or with a condenser.

To obtain an efficient turbine of this class it is, however, necessary that the velocity of the vanes should be nearly half that of the fluid of the impelling jet, a velocity so high (attaining 2,000 ft. per sec.) that special arrangements are necessary to render it possible. The wheel is fixed to the middle of a long, flexible shaft, one end of which is secured within a shaft carried in bearings, while the other end is carried in a long bearing having a spherical mounting; in this way the wheel is allowed to determine its own axis of rotation in somewhat the same way as does a spinning top. The speed of the shaft is so high, however, that it is unsuited to any ordinary machinery, and is accordingly reduced in one step by helical gearing in the ratio of 10 : 1, the countershaft then running at a speed suited for the direct driving of small dynamos; for slower machinery the reduction can be further carried out by belting.

This example gave off 5·37 brake h.p. at 3,000 rev. per min. of the belt pulley, when supplied with steam at 82·5 lb. pressure, and worked non-condensing.

A trial made in 1896 of a De Laval turbine for a New York central station, with a steam pressure of 147 lb. per sq. in. and a vacuum of 25·7 in. is recorded to have shown a water consumption of 17·3 lb. per brake h.p. per hour; the total power developed was 266 brake h.p. and the turbine disc made 9,000 rev. per min. The temperature of the inlet steam was 425 deg. C. and that of the discharge 40 deg. C. M.2931.

145. Parsons steam turbine (working). Made from drawings prepared in the Museum, 1907.

This type of compound turbine was introduced and patented by the Hon. Sir Charles A. Parsons in 1884 (*see* No. 143). The drawing shows a longitudinal section of a later and improved turbine for driving a dynamo having an output of 75 k.w., and the model represents a portion of the high-pressure end of it, showing the drum, casing, and blades.

The turbine consists of a shaft or drum of varying diameter having fixed to it a number of rows of blades or vanes, which alternate with similar rows set in the opposite direction and fixed to a surrounding casing. The action differs from that of the impulse type of turbine (*see* Nos. 144 and 146), in that the steam expands in the moving rows as well as in the fixed rows, so that there is a continuous fall of pressure throughout the annular channel of increasing area formed by the blade spaces. In order to utilise the energy of the steam efficiently and at the same time to keep the velocities low, the number of blade rows must be large. The first drum of the series, however, must be small on account of the full circumferential admission necessary and the small radial clearance allowable, but by increasing the diameter of the drum towards the exhaust end, the number of blade rows is decreased and the end blades shortened. The steam enters at one end and the resulting axial thrust, which in the early machines was obviated by making the turbine double ended, is balanced by drums formed on the shaft at the high-pressure end, corresponding in diameter to the several blade drums and having the same steam pressures acting upon them through passages in the casing. This reduces the length of the machine and increases its efficiency. The blades increase in size from the high-pressure end downward and also the axial clearances, which are nowhere less than 0·125 in. The blades are made of a special bronze, drawn in strips and cut to length; they are mounted in grooves turned in the drums and in the casing, with distance pieces between them, and the whole caulked tight. The grooves in the drum are slightly undercut or serrated. The shaft, where it passes out of the casing, and also the balance drums, are kept steam tight by labyrinth stuffing boxes or packings. These consist of a series of projecting collars turned on the shaft or drum alternating with a similar series of rings fixed in the surrounding casing and almost in contact with them on one face but with a large clearance on the other; this causes alternate throttling and expansion of the steam and prevents appreciable leakage. The shaft stuffing boxes are connected so that steam and not air leaks into the vacuum end. The shaft bearings are quite outside the turbine casing and are made slightly elastic by surrounding the brasses with a series of concentric sleeves fitting easily into one another, oil being supplied by a pump. Axial adjustment is provided for by a small thrust block at the end of the shaft. The steam is admitted through a double-beat valve actuated by a piston above it; its movement is controlled by a slide valve attached to one end of a lever the fulcrum of which is caused to oscillate by means of another lever and a cam driven by a worm on the shaft; the other end of the valve lever is controlled by a solenoid or by a centrifugal governor. The effect is that the steam is admitted in a series of puffs increasing in duration with the load until the flow becomes continuous. A runaway valve is fitted which cuts off the steam should the controlling apparatus fail.

In this machine there are three diameters of drum, 48 rows of moving blades, and an equal number of fixed blades varying in length from 0·5 in. to 1·75 in. The shaft runs at 4,140 rev. per min., giving a minimum blade speed of 100 ft. per sec. When using saturated steam of 140 lb. pressure and a vacuum of 27 in., it uses about 29 lb. per k.w. hour. A larger machine, however, developing 3,200 k.w. and using superheated steam, has shown a consumption of 14·1 lb. per k.w. hour. M.3504.

146. Model of Curtis steam turbine (working). (Scale 1 : 6., Made from drawings prepared in the Museum 1907. Plate III.) No. 5.

This type of steam turbine was patented by Mr. C. G. Curtis in 1896 and subsequently developed. The model represents a turbine for driving a dynamo of 500 k.w. output, made by the General Electric Co., U.S.A., in 1904.

The turbine is of the impulse type, in which the steam is wholly expanded in diverging nozzles and then has its kinetic energy absorbed by the blades of revolving wheels. In order, however, to reduce the peripheral speed of the wheels to a practical value, two methods are simultaneously employed; firstly the steam is expanded in two stages, by two sets of nozzles, and secondly, each wheel has three sets of blades with intermediate fixed guide blades which redirect the steam, after passing through one set, on to the succeeding sets. This combined method gives a large reduction in the peripheral speed with a small number of wheels and blades.

The turbine has a vertical shaft with bearings at the top and bottom, the whole revolving load being carried by a water-jacketed, adjustable footstep bearing which is supplied with oil under pressure. The turbine casing consists of three parts, one above the other, a diaphragm being placed between the two upper parts dividing the interior into two chambers in each of which one of the triple wheels revolves. The lower casing forms a pedestal containing the footstep bearing and the exhaust outlet. The shaft is fitted with stuffing boxes where it passes through the casings and diaphragm. The first-stage nozzles, twelve in number, are fitted in the roof of the top chamber and the guide blades are supported by a removable door which is adjustable. The second-stage nozzles are fitted to the under-side of the diaphragm and are forty in number to allow for the increased volume of steam. The guide blades occupy nearly the whole circumference and are fixed to the walls of the second casing, which is built up of four segments bolted together. Regulation is effected by a governor which closes or opens some of the first-stage nozzles; the second-stage nozzles are regulated by a large ring valve acting similarly, but operated by hand. The wheels are each built up of three steel discs, bolted together, and the blades are cut around the rims by special shaping machines; the passages thus formed are of constant width, but the depth, and also the blade angles, increase in accordance with the decreasing velocity of the steam. The guide blades are cut in the same way, in segments, and bolted to the casings. The dynamo is placed vertically above the turbine and directly coupled to it.

The turbine represented is designed for a steam pressure of 150 lb. per sq. in., and a vacuum of 28 in.; it runs at 1,800 rev. per min. and develops 670 electrical h.p. It uses about 15 lb. of saturated steam per h.p. hour, at full load, but with high superheat as low as 12 lb. Machines of this type have been built to develop more than twenty times the above power. M.3503.

147. Model of Rateau steam turbine (working). (Scale 1 : 4.) Made from drawings supplied by Messrs. Fraser & Chalmers, Ltd., 1908. Plate IV., No. 1.

This model, which is partly sectioned, represents a steam turbine of the form patented by Prof. A. C. E. Rateau in 1896, and subsequently developed. It is arranged for direct connection with a dynamo having an output of 600 k.w.

The turbine is of the compound or multi-stage impulse type, and consists of 14 simple turbines arranged in series in separate chambers, and with a common shaft. Each stage has a set of nozzles, in which the steam is expanded through a fraction of the total pressure drop, and a wheel which absorbs the kinetic energy thus generated; the steam enters at the high pressure end of the series and passes successively through all the stages to the condenser. The steam velocity ranges from about 750 ft. per sec. at the first wheel to about 1,100 ft. per sec. at the last.

The turbine is formed with a cylindrical casing of varying diameter, made in halves and divided by intermediate diaphragms into 14 chambers; this casing is closed and supported at each end by a cover, the upper half of which is separate, while the lower half forms part of a casting containing the

shaft-bearing. The shaft is of large diameter at the middle, and is stepped towards each end to form the wheel seats; it is carried in a long fixed bearing at each end, the bushes being of cast-iron, lined with white metal. A small thrust bearing is provided to keep the wheels in position and to take up any unbalanced axial pressure. The steam enters at the front of the central casing, through stop and regulating valves, and is led to the four first-stage nozzles that are fitted in the end cover. The nozzles for the succeeding stages are fitted into notches cut in the edges of the diaphragms, and they increase in circumferential length until at the exhaust end they occupy nearly the whole periphery. They are also placed in angular advance of one another so as to follow the helical course of the steam. The nozzles are built up of nickel steel plate for the first eight stages, and of brass for the other six. The first four wheels are single mild steel discs, riveted to flanges formed on hubs keyed to the shaft; the other ten wheels are formed of two slightly dished nickel steel discs, riveted one on each side of the hub flange, and also riveted together at the outer edge. The wheel blades are stamped from nickel steel plate and are of cylindrical shape with equal entrance and exit angles; they are formed with forked lower ends that are placed astride of the wheel discs and secured by two rivets. The outer ends are covered by a shrouding band secured by riveted projections on the blade ends; the steam entrance edges of the blades and nozzles are ground sharp. The wheels are balanced and tested before being placed in position. The diaphragms extend inward to the shaft, and are bushed with antifriction metal, which is grooved internally and fits closely over the wheel hubs. Where the shaft passes through the end covers stuffing-boxes are provided; these are double, and comprise an inner labyrinth packing formed with interlocking grooved bushes fitted to the shaft and cover, and running with small clearances; and an outer packing consisting of a pair of segmental cast-iron rings, fitted between end-plates, and held in contact wth the shaft by circumferential helical springs. The spaces between the packings at each end are connected together by a passage through the casing, so that steam leaking past the high pressure packing enters, instead of air, at the vacuum end. The turbine shaft is connected with the dynamo shaft by means of a flexible coupling. This consists of two flanges, having projecting bosses that keep them some distance apart, keyed to the shaft ends; these are drilled near the circumference to take 80 steel driving pins 0·3 in. diam. The pins are held in place by cover plates, and overstraining is prevented by stops, bolted to the bosses, which limit the relative motion. The bearings are supplied with forced lubrication and cooled by circulating water. Regulation is effected by means of a throttle valve, actuated by an oil relay, controlled by a centrifugal governor, driven by a worm and worm wheel from the turbine shaft. A large overload capacity is provided for by a by-pass that admits high pressure steam directly to the fifth set of nozzles. The turbine wheels range from 22·92 in. to 34·12 in. mean diameter; the axial clearance between the wheels and the casing is 0·12 in., while the radial clearance varies from 0·12 in. to 0·17 in.

The turbine represented is designed for a steam pressure of 160 lb. per sq. in., a superheat of 160 deg. F., and a vacuum of 28 in.; it runs at 3,000 rev. per min., and develops 800 h.p. When tested at full load it used 11·9 lb. of steam per brake h.p. hour, measured at the turbine coupling. A sectional drawing (scale 1 : 10) of the complete turbine is shown, together with specimens of the actual blades. M.3579.

148. Model of turbo-blowing engine. (Scale 1 : 8.) Made by Messrs. C. A. Parsons & Co., 1909.

This shows a steam turbine directly coupled to a rotary blower, for compressing air for blast furnaces or other similar purposes. A machine of this kind is simple, it can deal with a large quantity of air, and its delivery is perfectly steady.

The turbine is of the ordinary Parsons type (*see* No 145). The steam valves are mounted on the top of the casing and regulation is effected by the usual

puff gear controlled by a centrifugal governor. The oil for the bearings is circulated by a reciprocating pump, driven from the main shaft, the oil-tank being formed in the bedplate. The blower is a compound pump built on the same principle as the turbine itself, and embodies improvements patented by the Hon. Sir Charles A. Parsons in 1901. It has a number of rows of moving and stationary blades, fixed to the drum and casing, modifications being made in the shape and angles of the blades to suit the pressure conditions. The blades are of steel, flat on the delivery face and convex on the other face; the moving blades are set at an angle with the axis, while the stationary ones are parallel with it; they are indented at the roots and are caulked with distance pieces let into grooves cut in the drum and casing. A lacing strip is let into notches near the outer ends of the blades and there soldered; the blade tips are thinned down so that the clearances may be reduced to a minimum without fear of damage should the blades touch the casing or drum. A balance drum is provided to counteract the end thrust.

The machine shown runs at 3,000 rev. per min., and delivers 18,100 cub. ft. of air per min. at a pressure of 12 lb. per sq. in. Specimens of the actual blower blades and distance pieces are shown, together with a section of the drum having the blades mounted upon it. M.3595.

149. Westinghouse steam turbine. Lent by the British Westinghouse Electric and Manufacturing Co., Ltd., 1908.

This is a full-sized section showing the blading arrangement of a 4,000 k.w. steam turbine of the double flow combined type patented by Mr. G. Westinghouse in 1902–5.

The steam enters at the centre of the casing and flows towards both ends. It passes from an annular steam chest to a double set of nozzles in which the expansion is carried out from the boiler pressure to about 45 lb. per sq. in.; it is then delivered on to the blades of a double impulse wheel, with intermediate guide blades, without further change of pressure. The remainder of the expansion is carried out by 20 pairs of fixed and rotating blades, of increasing length, of the ordinary Parsons form. This construction, while sacrificing some efficiency at the high-pressure end, considerably shortens the turbine, obviates the use of balance drums, enables a drum of uniform diameter to be used, and requires no high pressure packing. The complete drum is about 56 in. diam. and is made of rolled weldless steel; it is mounted on three discs which are secured to a central shaft. The nozzles are formed of bent metal strips set in grooves in the sides of the circumferential slots which contain them. The high-pressure blades are of dropped forged steel, formed with shroud pieces and dovetail roots which fit into grooves cut in rings shrunk on the drum. The low-pressure blades, which are of special copper alloy, are set in slightly dovetailed grooves in the drum, and caulked tight with distance pieces in the usual manner; the longer ones are tied together, near their outer ends, by a wire of comma-shaped section passed through similar holes and with its tail turned over between the blades. M.3573.

150. Model of turbo-alternator. (Scale 1 : 12.) Made by Messrs. C. A. Parsons & Co., 1909.

This model represents a design for a large turbo-alternator for an economical output of 10,000 k.w., with a steam consumption of 13 lb. per k.w. hour, but capable of being overloaded to 20,000 k.w.

The turbine is of the ordinary Parsons type (*see* No. 145); the low-pressure end bearing is fixed to the alternator bedplate, while the high-pressure end is mounted on a separate one, upon which it can slide. The steam valves are mounted on the front of the lower half of the casing, so that the upper half may be removed without disturbing them. Oil is supplied to the bearings by a pump and returned to the oil-tank, which is placed under the turbine. The overload is provided for by a valve that admits high-pressure steam to

an intermediate point along the turbine. The alternator is of the stationary armature type, and is entirely enclosed by a casing, through which a cooling current of air is forced. The exciting dynamo is mounted on the end of the bed. M.3594.

151. Sectional drawing of 6,000 k.w. steam turbine. (Scale 1 : 12.) Presented by Messrs. C. A. Parsons & Co., 1912.

This drawing shows the internal construction of one of eight steam turbines which were built by Messrs. C. A. Parsons & Co., in 1909-10, for the Chelsea Power Station of the London Underground Electric Railways Co. at Lots Road (*see* adjacent prints).

These large turbines are now made with two separate casings, each with its own shaft and rotor, the shafts being in line and connected together by flexible claw couplings. This system enables each part of the turbine to have a short stiff shaft, reduces the size of the individual castings, and minimises the risk of distortion of the casings. The high-pressure portion has a solid steel shaft and drum with two diameters and 39 rows of moving blades; 50 per cent. overload is provided for by an automatic by-pass which admits steam at the thirteenth row of blades. The steam passes from the high-pressure casing, through a pipe, to the far end of the low-pressure casing, and flows through it in the reverse direction, exhausting at the centre of the machine. The low-pressure rotor is a parallel cylindrical drum mounted on two spiders on a solid shaft; it has 18 rows of moving blades, those in the last four rows being 12 in. long. Each shaft has its own thrust and adjusting block, and the bearings are of cast iron lined with white metal. The turbine is governed on the gust principle through a steam actuated relay, and there is a runaway valve that shuts off the steam if a certain speed is exceeded. The turbines run at 1,000 rev. per min., and, with steam at a pressure of 185 lb. per sq. in., a superheat of 140 deg. F., and a vacuum of 28 in., have shown a steam consumption of 14 lb. per k.w. hour. The high-pressure part develops about 40 per cent. of the full power. M.4016-8.

152. Sectional drawing of 500 k.w. combined steam turbine. (Scale 1 : 4.) Presented by Messrs. C. A. Parsons & Co., 1912.

This drawing shows the internal construction of the form of steam turbine in which the high-pressure steam is first expanded in nozzles and passed through a compound impulse wheel of the Curtis type (*see* No. 146) and then further expanded through a series of rows of blades of the ordinary Parsons reaction type. This form was introduced about 1902 (*see* No. 149), and is much favoured on the Continent; it reduces considerably the length of the machine, obviates the use of very short high-pressure blades, and relieves the main casing from the influence of the high pressure and temperature. The turbine has a solid forged steel rotor carrying 30 rows of reaction blading, while at the high-pressure end a large disc, which carries two rows of impulse blades, is bolted on. The nozzles are attached to a cast steel steam chest bolted to the main casing. The steam thrust is balanced by leading steam from the middle of the casing to the large end of the low-pressure drum. The shaft runs in brass bearings surrounded by sleeves fitted in cylindrical cast-iron housings, which are themselves mounted in the main bearing casings. A thrust and adjusting block is placed at the end of the shaft and is adjusted by sliding the bearing cap. M.4015.

153. Print of geared turbine for rolling mill. Presented by Messrs. C. A. Parsons & Co., 1912.

This shows a Parsons steam turbine of 750 h.p. constructed in 1910 for driving a rolling mill at the Calderbank Iron and Steel Works, Lanarkshire. The turbine is of the mixed pressure type, and is capable of using either exhaust steam at 16 lb. pressure from other engines, or high-pressure steam at 60 lb.

per sq. in. from the boilers. An automatic arrangement permits the entrance of the live steam when the exhaust supply is insufficient. The turbine runs at 2,000 rev. per min., and drives the mill through double helical gearing; the reduction is made in two steps, the first giving 375 r.p.m. and the second the required 70 r.p.m. for the mill. A flywheel 23 ft. diam. and weighing 90 tons is mounted between the gearing and the mill shaft. M.4021.

154. Sturtevant steam turbine. Made by the Sturtevant Engineering Co., Ltd., 1913. Plate IV., No. 2.

This is a small impulse turbine in which a low shaft speed is obtained by fully expanding the steam in divergent nozzles, and then passing it several times round the buckets of a single wheel. This arrangement, while not giving a high economy, is eminently suitable for driving small dynamos, pumps, blowers, etc., where a simple and reliable engine, needing little attention, is required. The idea of velocity compounding in a single set of buckets, although suggested 60 years previously, was first successfully applied by Prof. J. Stumpf about 1903. The machine shown, while resembling that of Stumpf, embodies improvements patented by Mr. O. O. H. Bentley in 1909, and in it the steam passes through the wheel a larger number of times.

The rotor is 12 in. diam., and is a steel forging having forty semicircular tangential buckets milled into the rim at an angle of 33 deg.; the bucket surfaces are ground and polished to minimise steam friction. The rotor is mounted on a horizontal shaft in a cast-iron casing consisting of a single casting and a cover. The main casting is provided with feet for bolting the turbine to its foundation, and two exhaust openings, either of which may be used, while the other is closed by a blank flange fitted with a relief valve; it has cast on it a bracket seat for one of the shaft bearings also. The cover, which is bolted to the main casting, is cast with an annular steam chamber which feeds the nozzles, and a seating for the other bearing. The steam supply enters through two governor valves arranged in series in a valve box bolted to a branch from the steam chamber.

The expanding steam nozzles, which are of rectangular section, are formed in bronze castings which also contain the guide buckets; they are bolted to the inner face of the casing cover and are curved to fit the wheel with a clearance of 0·062 in. The steam, after leaving the nozzle, enters the wheel buckets, gives up some of its energy, and is discharged in the reverse direction. It is then caught by the first of four semicircular guide chambers, milled in the nozzle casting, and returned to the wheel buckets, where it gives up more energy, and so on through the succeeding guides. It is passed thus five times through the wheel, the resulting bucket speed being only about one-fifth of that required with a nozzle alone. An additional guide bucket is added behind the nozzle to collect any steam that may miss the first, and this feature improves the efficiency considerably.

The shaft runs in ring-oiled white metal bearings mounted in spherical seats, and is fitted with metallic packings where it passes through the casing. An enclosed spring-controlled centrifugal governor is mounted on one end of the shaft, and this acts, through a bell-crank lever, on a balanced regulating valve placed in the steam pipe. An emergency governor, consisting of a spring held bolt placed transversely in the base of the main governor, flies out and releases a spring-closed throttle valve, if the speed should become excessive. The turbine shown has two nozzles, one of which is fitted with a stop valve, so that partial loads may be dealt with without loss of efficiency; it is rated at 5 h.p. with a speed of about 3,000 rev. per min., but, by increasing the number of nozzles to five the same machine will develop 25 h.p.

These turbines are made in various sizes up to 200 h.p. One giving 170 h.p. at 3,000 rev. per min. with steam at 180 lb. per sq. in., non-condensing, showed a consumption of 34 lb. of steam per brake h.p. per hour. With a vacuum of 20 in., this consumption would be reduced by 25 per cent.

Inv. 1913–10.

155. Model of steam turbine (working). Made in the Museum, 1909.

This is a working model illustrating the principle and arrangement of the compound reaction turbine of the Parsons type (*see* Nos. and). It consists of a revolving drum upon which are mounted two rings of curved blades ; two rings of similar blades are fixed to the casing and alternate with them, and the steam passes from the inlet end between the fixed and moving sets of blades alternately, while expanding. This arrangement of turbines in series reduces the steam and blade velocities, approximately inversely as the square of the number of rings of moving blades. In the model the casing is made of glass so that the blades may be seen. M.3641.

156. Model of steam turbine (working). Made in the Museum, 1909.

This is a working model illustrating the principle and arrangement of a steam turbine of the single stage impulse type. It consists of a single wheel mounted on a shaft, having symmetrically shaped blades round its periphery with an entrance angle of 30 deg. The turbine is driven by steam issuing from two nozzles, placed tangentially at opposite ends of a diameter, and making an angle of 20 deg. with the plane of the wheel. In the model the nozzles are cylindrical, as the exhaust pressure is much greater than one-half of the initial pressure, but in an actual machine using steam at ordinary pressure, a diverging nozzle is necessary in order to utilise efficiently the energy of the steam (*see* No. 144). M.3640.

157. Blading for Parsons steam turbines. Made by Messrs. C. A. Parsons & Co., 1909.

In the first Parsons turbine (*see* No. 143) the blades were straight, and were milled out of solid rings, which were afterwards fitted to the spindle and casing. Later on they were still of uniform thickness and milled in solid rings, but their shape was improved by bending them. In 1896, however, the Hon. Sir Charles A. Parsons patented the present form of blade and the method of fixing them in plain or serrated grooves cut in the drum and casing. The blades are made of drawn brass and have indentations formed across their lower ends; they are cut to length and inserted in the grooves with correctly shaped distance pieces between them, which are then expanded by caulking tools so as to grip the blades and the sides of the grooves. One or more notches are cut in the edge of each long blade, and lacing strips are soldered into them so as to increase the rigidity of the blades. The tips are thinned down in the manner patented by the Hon. Sir Charles A. Parsons and Mr. G. G. Stoney in 1905, so that, should the blades touch the casing, the tips simply wear down. In this way radial clearance may be reduced to a minimum without danger of stripping.

In order to assemble the turbines more rapidly, the blades, instead of being put in singly, are now made up into segments, consisting of a number of blades fastened together, and these are afterwards caulked into the grooves. Two methods of doing this are shown; in one, patented by the Hon. Sir Charles A. Parsons, Mr. G. G. Stoney, and Mr. D. F. Fullagar in 1899, and illustrated by a casing segment of 5·5 in. double-laced blades, the blades are set in notches milled along the side of a root strip, the metal between the notches being bent over so as to grip the blades, and the projecting corners afterwards levelled off ; the whole is then bent to the required curvature. The grooves for this method have to be wider than the blades. The other, known as the "rosary" method, consists in threading the blades and distance pieces on a wire, and building them up on a former into complete segments with the lacing strips attached; this is shown by a rotor segment of 3 in. blades with a single lacing strip.

Specimens are also shown of separate 3 in. and 5·5 in. blades of the rosary type, together with their corresponding caulking sections and lacing strips. M.3596.

158. Steam turbine details. Presented by Messrs. Fraser & Chalmers, Ltd., 1909.

These specimens illustrate a later form of blade construction used in the Rateau steam turbine (*see* No. 147).

The wheels are single steel discs, while the running blades are milled out of solid steel bars, and have forked-root ends that are placed astride of the disc, where they fit closely together; they are secured by countersunk rivets which pass through holes drilled between them, so that one half of each rivet is in each of two adjacent blade roots.

The guide blades are formed of drawn steel, and are set in cores of the mould for the diaphragm to which they belong; the latter is then cast round them. The diaphragm bushes are dovetailed in, and have V-grooves on their inner surfaces where they fit round the shaft. M.3709.

LOCOMOTIVES.—I.

For Common Roads.

In this section are collected the machines for moving objects upon public roads by the agency of other than animal power; it does not include the vehicles hauled, which are placed in the section devoted to transport appliances.

Self-propelled vehicles on roads can never attain the carrying capacity of those on the mechanically guided system of a railway, but their more extended range gives them an importance as transporting agents that will probably continue to increase. Many years, however, before the introduction of any form of railway locomotive, steam-propelled road carriages had been produced; but when Trevithick, in 1803, applied such a carriage to a tramway, the superior results gained on the special track caused the evolution of the railway locomotive to be much more rapid than the further development of the steam carriage.

The first practical horseless vehicle was the steam lorry built by Cugnot in 1763, which, in an improved form six years later, attained a speed of 2·25 miles an hour (*see* No. 159). Murdock in 1781 constructed several small and probably swift locomotive models (*see* No. 160), while in 1804 Trevithick produced the first steam-propelled road carriage that travelled faster than any horse-drawn vehicle; he built several other successful vehicles of the kind, as well as others specially suited for railways, in which connection his name is more generally known.

Sir Goldsworthy Gurney in 1827 constructed a steam coach, and three years later some of his coaches were successfully working a regular service between Gloucester and Cheltenham, (*see* No. 162). Between 1827 and 1834 Hancock, Dance, Church and others built some coaches, which had an average speed of about 12 miles and a maximum of a little over 20 miles an hour. They plied successfully as public vehicles in London and on some of the main coach roads till a sudden check was imposed upon their use by an Act being passed by Parliament permitting the im-

position of such heavy tolls on mechanically-propelled vehicles that in some cases the charges were twelve times those of a four-horse coach; at the same time, moreover, the development of the railway system with its higher speed absorbed so much general attention and enterprise, that by 1836 the steam road carriage was practically abandoned. In 1846–56, however, the heavy traction engine for agricultural and other purposes was introduced with great success. Progress was likewise checked, in 1865, by an Act limiting the speed of all mechanically-propelled vehicles to four miles an hour, in the country, and two miles an hour in towns, and requiring a man with a red flag to walk in front of the engine; these and other restrictions prevented any advance being made in this country in the construction of light road engines, although the steam traction engine developed continuously and became exceedingly useful.

On the Continent, however, Mons. Bollée introduced a steam car in 1875, and MM. Dion and Bouton built a steam tricycle in 1882. In 1884 Herr G. Daimler brought out his light and compact form of oil engine, which, in the following year, he fitted to a bicycle; in 1885 Herr C. Benz constructed his first oil-motor car and in 1889 Mons. L. Serpollet introduced his light steam carriage. Shortly afterwards some of these "automobiles" were imported into England, with the result that public attention was drawn to the existing restrictions, and in 1896 an Act was passed exempting from the low speed regulations vehicles weighing less than three tons when empty. A speed of 12 miles an hour was allowed for vehicles with a tare weight under 1·5 tons, and lower speeds proportionately for the heavier vehicles. A further Act in 1903 permitted an all round increase in speeds, the maximum being 20 miles an hour for vehicles having a tare weight under 2 tons; if fitted with resilient tires the heavier classes of vehicle are allowed higher speeds than those fitted with solid tires. This legislation has been a contributory cause to the progress that has been made in the power, speed and reliability of such vehicles. The internal combustion engine using petrol as fuel is the motor chiefly used, and although this necessitates the use of change-speed gearing, yet a large amount of flexibility and uniformity of turning moment can be secured by increasing the number of cylinders employed. Steam is generally preferred for the heavier class of commercial vehicles, while the use of liquid fuel has rendered successful its application to the lighter vehicles. Electrically driven cars, while possessing several advantages, are practically confined to use in towns.

159. Model of Cugnot's steam traction engine. (Scale 1 : 5.) Made by MM. Regnard Frères, 1892. Plate IV., No. 3.

Nicholas Joseph Cugnot, a French military engineer, in 1769 made a steam carriage somewhat like this model, which, travelling on a common road, and carrying four persons, attained a speed of 2·25 miles an hour, but, the boiler power being insufficient, the supply of steam failed after running for twelve or fifteen minutes. These results, however, induced the French Government, to order the construction of an engine for the transportation of artillery,

which should be capable of carrying a load of about 4·5 tons and maintaining a speed of 2·25 miles an hour on level ground. The machine, of which the model shown is a copy, was made in 1770 by Brézin to Cugnot's designs, at a cost of 800*l*., but was never tried, and is now preserved in the Conservatoire des Arts et Métiers at Paris. It consists of a heavy timber frame supported on three wheels and carrying in front an overhanging copper boiler. The front wheel has a broad, roughened tire, and is driven by two single-acting inverted vertical cylinders 13 in. diam. by 13 in. stroke. The two pistons are connected by a rocking beam, and their motion is transmitted to the driving axle by pawls acting on two modified and reversible ratchet wheels. The distribution of steam to the two cylinders is performed by a four-way cock actuated by a tappet motion. A seat is provided for the driver, who, by means of gearing, was able to steer the machine, the boiler and engines turning together as a fore-carriage through 15 deg. either way.

M.2445.

160. Murdock's locomotive model and drawing. Made in the Museum, 1894. Plate IV., No. 4.

This is a copy of the original experimental model made by William Murdock in 1781–6, and now in the Birmingham Art Gallery. At the time, Murdock was at Redruth, erecting pumping engines for Messrs. Boulton and Watt, and in August, 1786, the firm's agent writes, "Wm. Murdock desires me to "inform you that he has made a small engine of ¾ in. diam. and 1½ in. stroke, "that he has apply'd to a small carriage, which answers amazingly." In September of the same year, Boulton, in writing to Watt, says that Murdock "had made his steam carriage run a mile or two in Rivers's great room, making "it carry the fire shovel, poker, and tongs. William uses no separate valves, "but uses the valve piston, something like the 12 in. little engine at Soho, "but not quite." There is good evidence that, altogether, Murdock constructed three locomotives, the last of considerable size; but under pressure from Boulton and Watt, he ultimately abandoned the invention.

The model is carried on three wheels, a steering wheel in front, and two 9·25 in. driving wheels, connected by a cranked axle behind. The rectangular boiler is of copper with brazed joints, and has an internal flue. A metal cup to hold spirits is secured below the flue or fire-box, and so forms the grate. The steam cylinder is 0·75 in. diam. and double acting, with 2·125 in. stroke, and, with its valve chest, is partly sunk into the boiler. A small safety valve is seated on the cylinder flange, and loaded by a spring finger to retain the necessary steam pressure. A beam is carried by a post at the front end of the model, and at the other is connected with the piston-rod, while a connecting rod is carried down to the crank-pin of the driving axle. The steam valve is moved by the beam at each end of the stroke, by a tappet action. The valve consists of two pistons connected by a tube, the space between the pistons being always open to the boiler; the exhaust from the lower end of the cylinder escapes through the connecting tube. As the valve derives its motion from the beam, the engine will continue running in either direction when once started. Murdock placed rather too much of the weight on the driving wheels, and so to give stability and improve the steering added a weight over the steering wheels.

M.2413.

161. Original model of Trevithick's road locomotive. Woodcroft Bequest, 1903. Plate IV., No. 5.

Richard Trevithick (b. 1771, d. 1833), who, with other Cornish engineers, had been endeavouring to construct some form of stationary engine that would not be an infringement of Watt's patent relating to the condensing engine, decided to abandon condensation altogether, and by using steam of several atmospheres pressure to compensate for the portion of an atmosphere that he lost through having no condenser. The high-pressure engines which

he thus introduced were soon adopted for light winding and such work, where their compactness and simplicity were greatly in their favour. Having in this way gained some knowledge of the possibilities of this form of steam engine he appears to have constructed in 1797 a working model of a road locomotive; but if, as is probable, he had seen Murdock's earlier work in this direction, the chief merit of his model consisted in the higher boiler pressure it could carry and in the results it produced.

The model here shown is believed to be the original one made by Trevithick, and to have been left at the works of Messrs. Whitehead & Co., of Manchester, who were manufacturing actual engines for him in 1804. It has a vertical double-acting cylinder, 1·55 in. diam. by 3·6 in. stroke, sunk in the boiler; the piston-rod terminates in a guided crosshead, provided with connecting rods reaching down to crank-pins in the two driving wheels, which are 4 in. diam.; there is, however, a spur wheel on this crankshaft driving a pinion on the shaft of a fly-wheel, which it rotates at three times its speed. In addition to its controlling action, the fly-wheel forms a convenient arrangement for moving the engine off the dead centres. The steam distribution to the cylinder is controlled by a four-way cock driven by a tappet motion from the crosshead.

The boiler is cylindrical with a removable end, and contains a large oval flue, closed at the further end and fitted with a cast iron block, which, after being heated in an external fire and replaced, supplies the heat for generating steam; a small safety valve is added which is held down by a plate spring. The model is arranged with two expansible legs, by which the locomotive can be lifted off the ground and used as a stationary engine.

From the results obtained, Trevithick decided to construct the steam carriage, which he successfully tried on the roads at Camborne in 1801; it is believed to have weighed 1·5 tons, and to have had a speed of from 4 to 9 miles an hour. The general working was so satisfactory that, in 1802, Trevithick, and his cousin Andrew Vivian, patented a group of inventions relating to the high-pressure engine and its application to locomotion, while in the following year one of their steam carriages was working in the London streets. A modification of this engine, built by Trevithick, and successfully tried in 1804 on the Penydarran tramway, was the first form of railway locomotive (*see* No. 184). M.1835.

162. Print of Gurney's steam carriage. Presented by Miss A. J. Gurney, 1876. Other prints received 1900, 1904 and 1909.

Sir Goldsworthy Gurney began his work on motor carriages in 1823, and in 1825 patented an arrangement of pushing struts or legs as a means of propulsion, together with a water-tube boiler, while by 1825–6 he had completed a carriage in which these features were embodied. In 1827 he patented a steam coach having six road wheels, the front pair, which the driver steered, being connected with the pole of an ordinary fore-carriage to control it; this peculiar steering arrangement is stated to have been so satisfactory that it could be worked by a child. The two steam cylinders were arranged on perches below the coach body, and drove the rear wheels which were loose on their axles, the connection to one or both being by bolts in a circular plate on the outer ends of the axle and engaging in the nave; a gab valve gear was used for reversing. Superheated steam was supplied by a boiler placed in the hind boot; it was composed of U-shaped tubes about 1 in. bore, the lower legs of which formed the fire-bars and were connected with a water drum, while the upper ends opened into a steam drum; the drums were further connected by a number of vertical pipes or down-comers. The draught was produced by a fan driven by a separate engine.

A coach embodying most of these features, including legs for hill-climbing, was built towards the end of 1827, and is represented in the top print and in another one adjacent. The rear wheels were 60 in. diam., the front ones 45 in., and the pilot wheels 36 in. Coke was the fuel employed, and sufficient for one stage was accommodated in the furnace, while 60 gal. of water were taken

in a tank below the coach body. Steam separators were arranged behind the chimneys at the rear, and a steam jet, which was Gurney's invention, was used to force the draught. The vehicle weighed about 2 tons when empty, and would accommodate six passengers inside and twelve outside; it is stated to have attained a speed of 15 miles an hour.

In one of the prints a succeeding carriage is represented ascending Highgate Hill in 1828; in it Gurney had abandoned the use of propelling legs.

The bottom print represents a steam drag or "tractor," constructed by Gurney in 1829 for hauling a carriage in which the passengers were conveyed. The general arrangement was similar to that of his coach, and the driving wheels were rotated by double arms keyed on the crankshaft, and acting against pins projecting from the felloes, so as to give the necessary play. The boiler worked at a pressure of from 70 lb. to 120 lb. per sq. in., and the draught was produced by a steam jet, but it differed from the earlier form in having horizontal instead of vertical separators. The tractor was steered by a hand wheel, rotating a pinion gearing into a segmental rack. The print represents this steam carriage returning from Bath, August 12th, 1829, when it was met at Hounslow Barracks by the barouche of the Duke of Wellington, which was then attached in place of the trailer. The whole distance of 84 miles had been travelled in 9·3 hours, including stoppages, and the normal speed was 14 miles an hour.

Gurney's carriages were taken over and improved upon by Sir Charles Dance, who, from February to June, 1831, ran with them a regular service four times a day between Gloucester and Cheltenham (9 miles), as well as journeys upon other roads (*see* print in adjacent frame); the speed, including stoppages, was from 10 to 12 miles an hour. His enterprise was abruptly stopped by systematic obstruction of the roads, and by the imposition of excessive tolls, which in some cases formed one-half of the working expenses.

M.1420, 3331, 3631-2.

163. Print of Hancock's steam omnibus. Presented by George Ellis, Esq., 1858.

Between 1827–38 Mr. Walter Hancock, of Stratford, built nine steam carriages of various types, all of which were mechanically successful, although ultimately abandoned. In 1832 he started a regular service of steam omnibuses between Paddington and the City, and the vehicle represented was built for this work in 1833.

One of the best of these steam carriages weighed about 3·5 tons and carried sixteen passengers; it accomplished a run from Stratford to Brighton in 8·5 hours, including 2·5 hours lost in stoppages. There were two vertical steam cylinders, 9 in. diam. by 12 in. stroke, driving a crank-shaft which, by pitch chain, was connected with driving wheels 48 in. diam., but the gearing virtually reduced them to 24 in., so that the tractive factor was 40. Steam was supplied by a sheet-flue boiler 2 ft. square and 3 ft. high, arranged over a grate which had a closed ash-pit and a fan draught. M.2770.

164. Print of Church's steam carriage. Presented by R. B. Prosser, Esq., 1900.

Mr. William Church in 1832–35 patented certain constructions of steam carriage, and introduced two forms of vertical boiler for supplying the steam; he also advocated the use of wheels with flexible arms and very broad but elastic rims. In 1832 his steam carriages ran between London and Birmingham, but the opening of the railway finally diverted the traffic. Two views are shown of his ornamental three-wheeled steam coach, and there is a perspective view of what is probably a proposed enlarged form of the vehicle, intended to carry fifty passengers. M.2962.

165. Print of Squire and Maceroni's steam carriage. Presented by R. B. Prosser, Esq., 1900.

Messrs. Squire and Maceroni in 1833 patented a form of water-tube boiler, consisting of a mass of vertical tubes, which formed also a firebox shell; the lower or water ends of the tubes were connected, and the upper ends communicated with a steam drum. The drawing shows a carriage driven by two horizontal cylinders acting directly upon the cranked hind axle, which carries the driving wheels; forced draught is supplied by a fan worked from a pulley on one of the driving wheels. Several of these carriages were made, and they regularly ran at an average speed of 14 miles an hour, while the maximum was 20. The body was that of an open coach and seated eight passengers.

M.2962.

166. Print of Hills's steam carriage. Presented by R. B. Prosser, Esq., 1900.

Between 1839–43 Mr. F. Hills patented several forms of multitubular and water-tube boilers with vertical shells or cases; he also described a steam coach fitted with such boilers. The cylinders were vertical and close to the boiler, which was behind with an overhanging platform for the stoker.

M.2962.

167. Locomotive for ice. (Scale 1 : 8.) Contributed by Nathaniel Grew, Esq., 1862.

This represents the engine "Rurik," built in 1861 by Messrs. Neilson and Co., at Glasgow, for use on the frozen Neva. For many winters the engine performed a regular passenger and mail service between Petrograd and Cronstadt; the train that it hauled consisted of three railway coaches mounted on sleigh irons. The track was a cleared one, provided with telegraph wires and signals; the locomotive, however, sometimes travelled into the country on the sleigh roads.

The engine has a locomotive boiler, with the feed water in a saddle tank above it, and a large footplate on which fuel is stored. There is a single pair of driving wheels 5 ft. diam., driven by a pair of cylinders 10 in. diam. by 22 in. stroke, giving a tractive power of 36·6 lb. per pound of mean pressure in the cylinders. The connecting-rods drive an intermediate shaft, on which are the eccentrics, and this is connected with the drivers by coupling-rods. The front of the engine is carried on a sleigh with interposed springs, and steering is done from the front platform by worm gearing that turns the sleigh round a pivot near its end. In working trim the total weight is 12 tons, but the grip of the drivers is increased by steel spikes that project from their rims and enter the ice.

M.848.

168. Model of a traction engine. (Scale 1 : 12.) Contributed by Messrs. Gardener and Mackintosh, 1865.

This engine, patented by Messrs. R. Longstaff and A. Pullan in 1859, has two inclined cylinders driving cranks at right angles. The crank-shaft by a two-speed gear is connected with the intermediate shaft, which, by overhanging pinions, gears into spur rings on the large travelling wheels. The intermediate shaft is arranged vertically over the driving wheels, so that the motion due to the action of the bearing springs shall not interfere with the working of the spur gear. To distribute the weight when travelling on soft roads two small wheels are carried between the large drivers and are driven by teeth from their peripheries, but these additional bearing wheels can be raised above the road surface and out of gear when travelling on hard ground. Independent framing is employed to carry the mechanism so as to reduce the strains on the boiler.

Steering is done from a front platform by a hand-wheel, which, by pitch chain, turns the fore-carriage.

M.716.

169. Model of a traction engine. (Scale 1 : 10.) Lent by Messrs. Aveling and Porter, 1889.

This model is incomplete, but there is sufficient to show the special features of the arrangement, which were patented by Mr. T. Aveling in 1861 and 1870.

The single steam cylinder is placed on the front part of the boiler, and is surrounded by a jacket in direct communication with it; the steam is admitted into the cylinder from a small dome on the top, to which the safety valves are fitted. The side plates of the fire-box are extended upward and backward, and to them the bearings for the crank-shaft, counter-shaft, and the driving axle are fitted. The driving wheels, which carry about 85 per cent. of the total weight of the engine, are fitted with a bevel wheel compensating gear, to give differential motion when turning. The engine is steered from the foot-plate, through a worm, worm shaft and chains, by the hand-wheel shown.

M.2277.

170. Model of a steam road roller. (Scale 1 : 10.) Lent by Messrs. Aveling and Porter, 1899.

This is a form of road locomotive in which, by the provision of wide-faced wheels completely covering the surface of the portion of the road passed over, the loose road metal is levelled and at the same time consolidated and interlocked in a way that greatly conduces to its future durability, as well as immediately reduces the labour of draught animals passing over it. The steam roller was patented by Messrs. W. Clark and W. F. Batho in 1863, and improved by Mr. T. Aveling in 1867, while the form shown was patented by the latter in 1871. The roller is also used for hauling a scarifier, for breaking up roads requiring repair.

The boiler is of the locomotive type and is prolonged in front by a casting that forms the base of the chimney and the housing for the top of the fork carrying the front rollers. This housing permits of a sideway swing of the fork, so that these rollers shall bear equally, and admits of the turning movement necessary in steering. The hind axle passes behind the fire-box and is connected with the driving wheels by independent removable pins.

The engine represented has a single steam cylinder, which is completely steam-jacketed, and is fitted with the usual link-motion reversing gear; the crank-shaft is carried by outside bearings secured to upward prolongations of the external fire-box sides, and by this extension the bearings of the two intermediate countershafts are also carried. There is a sliding sleeve on the first countershaft by which two different speeds of gearing can be obtained; in the intermediate position the crank-shaft is left free, for use when power is taken from the fly-wheel only. From the second countershaft the power is directly transmitted to a spur wheel, concentric with the driving axle. Projecting backward from the fire-box is a water tank, the sides of which extend upwards so as to enclose the foot-plate and form also a coal bunker; there is another water tank under the barrel of the boiler in front of the fire-box, and to this tank the steering mechanism is attached.

Steering is performed from the foot-plate by a hand-wheel which, by worm gearing, controls two chains connected with the fork of the front wheels; all of the road wheels or rollers are fitted with scrapers. A strap brake, forced on by a screw, is provided for use should occasion require exceptional retaining power. The boiler is fitted with a feed pump on one side and an injector on the other.

These rollers are made in six sizes weighing from 6 to 20 tons and rolling a road width of from 4·75 ft. to 8·25 ft. M.3054.

171. Photograph of Serpollet steam carriage, 1889. Prepared in the Museum, 1914.

Mons. L. Serpollet invented his flash boiler, or instantaneous steam generator, in 1887, and applied it shortly afterwards to a steam-driven

tricycle. This was so successful that he constructed, in 1888–9, first a larger tricycle, and then some three-wheeled carriages, one of which is here represented.

This carriage seated four persons and was driven, through gearing and a single chain, by a two-cylinder horizontal engine of ordinary form. The boiler consisted of two spiral coils of thick flattened tubing placed over a furnace into which coke fuel was automatically fed from a hopper. The steam was highly superheated and the exhaust was also heated so as to render it invisible; the chimney was turned downwards and terminated near the roadway. The engine was controlled entirely by the amount of feed water pumped into the boiler, there being a regulating valve which passed either the whole or part of the pump discharge into the boiler, the remainder passing back into the tank. A hand pump was used for starting and for increasing the power on hills. The car attained a speed of about 16 m.p.h. Inv. 1914–727.

172. Steam car engine and boiler. Made by the Locomobile Co., U.S.A. Received, 1914.

This is the power portion of a "Locomobile" light steam car, large numbers of which were imported about 1900. The special form of boiler used was patented by Messrs. F. E. and F. O. Stanley in 1899.

The boiler consists of a cylindrical drum 14 in. diam. and 13 in. long; this is formed of a copper shell and two steel end plates joined by nearly 300 copper tubes 0·437 in. diam. The shell is strengthened against bursting by steel piano wire wound round it under tension, and its flanges are supported by steel rings through which the rivets pass. The heating surface is 30·25 sq. ft. Below the lower tube plate is a firebox containing the petrol vapour burner. This consists of a shallow cylindrical chamber with a number of short copper pipes passing through it; the top plate of the burner has numerous small holes drilled through it round the top of each pipe, and these form jets from which the petrol vapour in the chamber escapes under pressure, causing induced currents of air through the pipes, so forming a combustible mixture which burns with a very hot blue flame. The petrol is stored in a tank, under air pressure, and passes through a heating coil in the firebox on its way to the burner. The quantity of fuel is controlled by an automatic regulator which, by the steam pressure acting on a diaphragm, cuts down the fuel supply as the pressure rises. The burner is started by means of a "firing iron," which consists of a loop of pipe fitted with a vapour nozzle and fuel connection; this is made red hot, inserted in the firebox and connected up. The fuel passing through the hot pipe is vapourised and passes to the burner where it may be ignited. When the boiler is hot enough, the main fuel nozzle is put into operation and the firing iron is removed. The feed water enters at the lower tube plate after passing through an exhaust steam heater which also serves as a muffler. Water and pressure gauges, stop and safety valves are fitted. The steam pressure is 150 lb. per sq. in.

The engine has two vertical cylinders 2·5 in. diam. by 3·5 in. stroke, and runs at a normal speed of 400 rev. per min.; with a mean pressure of 100 lb. it would develop 7 h.p. Ordinary slide valves and Howe link motion are used, and the crank shaft and connecting rods are fitted with ball bearings. A feed pump is mounted on the frame, and its plunger is driven by a lever from one of the crossheads. The crankshaft has a sprocket wheel at its centre, and from this a pitch chain drove the rear axle of the car. The engine is mounted on hinges bolted to a cross member of the frame and its lower end was connected with the rear axle by an adjustable radius rod.

The exhaust steam was passed through the muffler and thence into the chimney which was turned downwards through the water tank behind the boiler. The throttle and reversing levers are mounted at the right hand side of the seat, and there is also a feed by-pass lever by means of which the pump delivery is controlled, the water that is not needed by the engine passing back into the water tank. Inv. 1914–630.

173. Photographs of early Benz motor car. Presented by the Brompton Motor Co., Ltd., 1913.

Although Daimler invented the light high speed spirit motor, it was Carl Benz, of Mannheim, who first successfully applied such motors to light and practical road vehicles. Benz built his first car, shown in the photographs, in 1885, and patented it in the following year, and its direct successors, many of which were made and sold between that date and 1900, did more, perhaps, than any others to demonstrate the possibilities of the motor car.

The car was a two-seated, three-wheeled vehicle with wire wheels and solid rubber tires. The motor was placed over the rear driving axle, and had a single horizontal cylinder with a vertical crankshaft carrying a large fly-wheel. At the top end of the crankshaft a bevel wheel was fitted which drove a horizontal shaft at half the speed; this shaft carried a wide pulley which was connected by a belt with fast and loose pulleys mounted on a countershaft, fitted to the frame, in front of and at the same level as the driving axle. The counter-shaft was divided and fitted with a differential gear, while its ends carried sprockets that were connected with the driving wheels by chains. The front wheel was mounted in a vertical fork, and was steered by a short hand lever through a rack and pinion gear. The rear axle was fitted with elliptical springs. The belt was shifted by a lever that also applied a brake to the fast belt pulley. The explosive mixture was supplied by a surface carburetter and a mixing valve, the ignition was by coil and battery, and the cylinder was water cooled on the thermo-siphon system. The car was rated at about 0·75 h.p. It is now preserved in the Deutsches Museum at Munich. Inv. 1913–67.

174. Benz motor car, 1888. Made by Messrs. Benz & Co. Received 1913.

Following his first three-wheeled car (*see* No. 173), Carl Benz built a few larger and more powerful cars of the same general type, but he found considerable difficulty in finding a market for them until, in 1888, Mons. E. Roger exploited them in Paris. The car shown is one made by Benz about 1888 and sold by Roger, and it is probably the first petrol car brought to England.

The car is a four-seated, three-wheeled vehicle with wooden wheels; the rear driving wheels have iron tires and the front steering wheel was originally fitted with a solid rubber tire. The motor is of the four-stroke type and is placed horizontally over the rear axle; it has a single cylinder 116 mm. (4·57 in.) diam. by 160 mm. (6·3 in.) stroke, and when running at 250 to 300 r.p.m. would develop about 1·5 h.p. The crankshaft is placed vertically because it was thought that the gyroscopic action of a vertical fly-wheel would adversely affect the steering, but this arrangement was abandoned as unnecessary about 1890. The lower end of the crank-shaft carries the fly-wheel and is supported on a footstep bearing carried by a transverse member of the frame. To the upper end of the shaft a bevel wheel is fitted which gears with an equal wheel on a horizontal shaft that carries at its end a wide belt pulley. This shaft drives by spur gearing, at half the speed, a parallel shaft on which the cams for the valves and ignition are mounted. The exhaust valve is of the mush-room type and is fitted in the water-jacketed cylinder head, while the inlet is a slide valve fitted to the side of the cylinder. The explosive mixture is supplied by a surface carburetter in which the level of the spirit is maintained by dropping into it, from a storage tank under the seat, small quantities of spirit by means of a hollow plug valve slowly rotated by the engine. A mixing valve is placed between the carburetter and the inlet valve for diluting the mixture as required. The ignition is by battery, coil and sparking plug, but Benz originally tried a dynamo driven by a belt from the fly-wheel. The cylinder is water-cooled on the thermo-siphon system, the water circulating through the jacket and a radiating tank above it. As the water boils away it is replaced by cold water from a tank under the seat. The exhaust gases are passed through a silencer, part being directed into the false bottom of the carburetter.

The engine pulley is connected by a belt with fast and loose pulleys mounted on a countershaft fitted to the frame in front of the driving axle. The countershaft is divided and fitted with a differential gear, while its ends carry sprockets that are connected with the driving wheels by chains. A chain-drive two-speed gear is also fitted to this shaft. The front wheel is mounted in a vertical fork and is steered by a short hand lever and a double rack and pinion. The fork is connected with the rear axle by two perch bars forming with the axle an underframe from which the carriage frame is supported by three elliptical springs, one to each rear wheel and a transverse one in front. The frame is built up of iron tubes and the motor is suspended from a transverse tee iron. The chains are adjusted by moving the countershaft, the rear axle being tied to the frame by radius rods. Wooden brake-blocks are applied to the driving wheel tires by a hand lever with which is incorporated the belt shifting lever. The driving seat is set across the middle of the frame and is fitted with a hood; a reversed seat for two persons is placed at the front end. The mechanism is protected by a body with wooden sides, back doors, and a leathern top.

The driving wheels are 49·5 in. diam., the leading wheel is 30 in. diam., and the wheel base is 5·17 ft.; the wheel track is 3·87 ft. The car runs at about 10 and 5 miles an hour respectively on the two speeds, and is still in working order. M.4229.

175. Panhard and Levassor motor car, 1894. Presented by the Royal Automobile Club, 1910. Plate VI., No. 6.

The modern motor car was rendered possible mainly by the invention, in 1884, by Gottlieb Daimler, of the light high-speed petrol motor. This motor, in the form patented by Daimler in 1889, was taken up by Messrs. Panhard and Levassor, who applied it to road carriages and developed a successful design, the arrangement of which has been followed generally ever since. The car shown was made in 1894, and brought to England by the Hon. Evelyn Ellis, in the following year.

The mechanism of the car consists of a two-cylinder motor, placed in front on the centre line of the car, and driving a longitudinal shaft through a friction clutch; this shaft drives another one, above and parallel to it, through a change-speed gear, and this drives, through a bevel gearing, a transverse shaft having sprocket wheels on its ends, which are connected with the rear road wheels by chains.

The motor runs at 800 rev. per min. and develops 4 h.p.; it has two cylinders 75 mm. (2·95 in.) diam., by 140 mm. (5·51 in.) stroke, placed in a transverse vertical plane and inclined at an angle of 15 deg. to one another. The motor works on the Otto cycle and both pistons are connected with the same crank pin, so that they work together, but an explosion takes place in each cylinder alternately. The inlet valves are automatic, while the exhaust valves are operated by a double cam groove cut in the face of one of the crank discs, which causes the valves to lift once in two revolutions. The cam rods have hinged pieces at their upper ends which are normally in line with the valve spindles, but should the engine race, a lever, connected with a centrifugal governor, engages with arms on these pieces and turns them aside so that the exhaust valves remain closed. The same operation may also be performed by hand. Hot-tube ignition is employed, petrol flames being used to heat the platinum tubes. The carburetter is of the float feed spray type patented by Mr. W. Maybach in 1893, and the air supply may be heated by passing it through the ignition tube casing. The cylinders are cooled by water jackets, the water being passed through them from the storage tank by a semi-rotary pump driven by a crank which is rotated by a worm on the engine shaft.

The motor shaft has the hollow member of a cone clutch secured to its end, while the other leather-faced member is fixed to the forward end of a longitudinal shaft which slides in its bearings and is held in contact by a spring pressing on its rear end; it is drawn out of engagement by a pedal. Above this shaft is another one having four spur wheels of different sizes fixed to it; the lower shaft carries a sliding sleeve having four corresponding

wheels, which can be moved by means of a hand lever, so that either of the four pairs may engage, thus giving speeds of 3, 7, 11 and 15·5 miles an hour respectively. The lower gear-wheels are of steel and the upper ones of gun-metal with steel rims riveted to them on which the teeth are cut. The upper shaft carries a bevel-wheel at its rear end which gears with one of two bevel wheels mounted on the transverse countershaft. These bevel wheels are fixed together with the differential gear between them and they are moved laterally, by means of a hand lever, so that either of them may engage, thus giving a forward or a backward motion.

The rear wheels run loose on their axle, which is fitted with semi-elliptical plate springs and tied to the frame by radius rods; they are driven from the countershaft by pitch chains, the chain wheels being bolted to the wheel spokes. A band brake is fitted on the countershaft and operated by a pedal; brake blocks are applied to the driving wheel tires by a hand lever and an application of either brake automatically disengages the clutch. The front axle is fitted with elliptical springs and has pivoted ends carrying the wheels which are steered by a tiller. The petrol tanks and lubricator are mounted on the dashboard. The exhaust gases are led beneath the frame to a silencer through which they are discharged.

The car frame is built up of compound wood and iron members, while the motor and gearing are carried by an auxiliary iron frame bolted to it. The wheels are of wood and fitted with solid rubber tires. A four-seated body is fitted to the frame, a wooden casing encloses the motor, and a leathern shield is hung below the gearing. The driving wheels are 42 in. diam., and the leading ones 31·5 in. diam.; the wheel base is 5·46 ft., and the width of track 4·42 ft. The overall length of the car is 9·42 ft., its width is 5·5 ft., and its weight about 15 cwt. M.3746.

176. Benz motor car, of 3 h.p., 1898. Made by Messrs. Benz & Co. Received 1912. Plate IV., No. 7.

This is one of the small Benz cars which succeeded the earlier three-wheeled vehicles (*see* Nos. 173 and 174). These cars retained the general features of the first, and over 4,000 of them were built between 1893 and 1900; the original arrangement was, however, abandoned about 1902, and Benz cars are now of the standard type. The car shown was built in 1898, and its mechanism consists of a single cylinder horizontal motor, with a transverse shaft, placed over the rear axle; this drives, by pulleys and belts, a countershaft having sprocket wheels on its ends, which are connected with the driving wheels by chains.

The motor has a cylinder 110 mm. (4·33 in.) diam. by 110 mm. stroke, and develops about 3 h.p. when running at 600 rev. per min. It works on the Otto cycle; the inlet valve is automatic, and the exhaust valve is operated by a cam fixed on a half-speed shaft driven from the crankshaft by spur gearing. The cam is double, and the roller that bears against it can, when starting, be moved laterally, so that the second part of the cam acts on the exhaust valve and opens it slightly on the compression stroke. A second inlet valve is placed in the cylinder head, and this admits air, and prevents the formation of a vacuum in the cylinder, when running with the throttle nearly closed. Electric ignition is employed, the accumulators and induction coil being carried under the seat. The contact-maker is mounted on the half-speed shaft, and the time of ignition may be varied by altering by hand the angular position of the wiper. The carburetter is of the surface type, and consists of a vertical cylindrical vessel containing the petrol, the level of which is kept constant by a valve and float. Air entering at the top of the chamber passes down a pipe and sweeps over the surface of the petrol, so producing a very rich mixture, which passes out through a gauze-covered pipe to the mixing valve. This valve has adjustable air and mixture passages, so that the quality of the explosive mixture can be controlled at will. The quantity passing to the motor is regulated by a hand throttle-valve, no governor being fitted. The petrol, which is stored in a tank beneath the seat, is heated by a part of

the exhaust gases passing through the false bottom of the carburetter. The cylinder is cooled by a water jacket which is in communication with flat storage tanks forming the sides of the body. The water is boiled away and the steam rises to an air condenser placed behind the seat; the condensed water flows back to one of the tanks. The exhaust gases are discharged through a silencer.

The motor shaft carries a fly-wheel, two pulleys of different diameters and a bevel wheel for the hand-starting gear, which has, however, been removed. The countershaft is mounted in ball bearings having horizontal adjustment, and upon it is mounted a belt pulley, with two diameters, within which the differential is fitted; loose pulleys are placed beside the others, and belt striking gear is provided, so that either of two crossed belts may be brought into action, thus giving two different speeds to the countershaft. When both belts are on their loose pulleys the motor runs free. A third pulley on the countershaft contains an epicyclic gear, which gives a third low speed when held stationary by a band brake. The speeds given, with the normal engine speed, are 14, 6 and 2·6 miles an hour, and the changes are effected by means of three handles mounted beside the steering pillar.

The driving wheels run loose on their axle, which is fitted with elliptical springs; they are driven from the countershaft by pitch chains, the chain wheels being bolted to the spokes. Band brakes, applied by a pedal, are fitted to drums attached to the hubs, and brake blocks are applied to the driving-wheel tires by a hand lever. The front axle is fitted with elliptical springs, and has pivoted ends carrying the wheels which are steered by a handle at the top of a vertical pillar; a pinion at the foot of the pillar engages with rack bars connected with the steering rods. The axles are tied together by a bar at each side. The throttle and mixture valve controls, as well as the ignition switch, are at the front of the driver's seat, which is on the left side.

The car frame is built up of compound wood and iron side members, with crossbars of angle and tee-iron, upon two of which the motor is carried; the wire suspension wheels are fitted with ball bearings and solid rubber tires. A two-seated body, fitted to the rear of the frame, encloses the motor, access being obtained through a door at the back; a small reversed seat is also provided at the front of the car. The driving wheels are 36 in. diam. and the leading wheels, 24 in. diam.; the wheel base is 4·25 ft., and the width of track, 3·66 ft. The overall length of the car is 7·33 ft.; width, 4·33 ft.; weight, about 8 cwt. M.4087.

177. Model of petrol motor car chassis (working). (Scale 1 : 4.) Made by Messrs. T. & C. J. Coates from drawings prepared in the Museum, 1904.

This represents the complete framework and mechanism of a typical petrol-propelled car when a live driving axle is employed; the other arrangement, now almost obsolete, is that in which the axle is fast and the driving wheels are rotated by separate pitch chains. The motor is placed in front, with its crankshaft on the longitudinal centre line and driving a central shaft by a friction clutch and change speed gear, through which the power is transmitted to the rear axle by a shaft and bevel gearing.

The motor is of the ordinary vertical type, with two cylinders each 100 mm. (3·9 in.) diameter by 132 mm. (5·2 in.) stroke, working on the Otto cycle and driving opposite cranks; when running at 900 rev. per min. it develops 10 h.p. The mixture of petrol vapour and air is derived from a float-feed carburetter, while the main air supply is heated by the exhaust gases; a centrifugal governor fixed to the half-speed or valve shaft controls the supply of the explosive mixture to the cylinders, but when extra power is required this mechanism may be thrown out of action. Ignition of the charge is performed by high tension electric sparks, timed by a rotary switch secured to the valve shaft, which pass between terminals arranged in the cylinder heads; the electricity is supplied by accumulators, through an induction coil,

and the period of ignition is adjustable by moving the stationary switch contacts round the shaft. The cylinders and heads are cooled by jackets into which, by a rotary pump, water is forced and then sent through a radiator of gilled pipe placed on the front of the car, so that it may be cooled by the air before again entering the cylinder jackets.

The fly-wheel of the motor is recessed so as to form one member of a cone clutch, the other member of which is a leather-faced cone sliding freely on the squared end of a short first-motion shaft but pressed into driving contact by a spring whose action may be moderated or neutralised by a pedal.

The change-speed gear, which is of the Panhard type, consists of a sleeve provided with three spur wheels of different diameters and capable of being moved along a squared portion of the first-motion shaft, while parallel with, but below the sleeve, is the second motion-shaft, upon which are secured three corresponding wheels so spaced that by sliding the sleeve the transmission can be effected through either of the three gears. The position of the sleeve is controlled by a hand lever, and the gears are such as to give speeds of 8, 12 and 16 miles an hour when the motor is running at its normal governed speed of 800 rev. per min.; at the lowest speed the motion of the car can be reversed by a pedal which introduces into the gear an intermediate wheel.

To allow for the difference in the lengths of the paths described by the driving wheels when the car is turning, these wheels are independently but simultaneously driven by the arrangement of differential gear introduced for the purpose by Roberts in 1832. This is carried out by making the rear axle in two lengths and securing a spur wheel to the inner end of each; these wheels are then enclosed in a box, or arm, which carries two pairs of wide-faced spur pinions loose on the spindles but gearing together and with the axle wheels. This gear box has fixed to it a bevel wheel, gearing with a pinion fixed to a short shaft carried by a stationary outer casing and driven from the second motion-shaft by a longitudinal shaft provided with Hooke's joints at its ends. When the car is moving in a straight course the wheels and pinions with their box revolve as a whole, but when describing a curve the driving wheels rotate at different speeds, owing to the pinions being free to revolve and thus allowing the outer wheel to go faster and the inner one slower than the mean speed. The axles of the driving wheels run in ball bearings and are enclosed in tubes screwed into the central gear casing, while the springs of the vehicle are attached to these tubes. The driving wheels are fitted with band brakes, applied by a lever which simultaneously releases the driving clutch, and there is a pedal brake on a drum on the second-motion shaft.

The car is steered by the front wheels, which are mounted on short independent swivelling axles, so connected that, when turning, the tracks of the four wheels have approximately the desired common centre. This device was proposed by Du Quet for some windmill carriages in 1714, was re-invented by Lenkensperger in 1818 for horse-drawn vehicles, and was patented in England by Ackermann: in 1832 it was applied by Redmund to a steam carriage. This arrangement avoids the tendency of a swivelling fore-carriage to turn when one wheel meets an obstruction (a tendency which in a horse-drawn vehicle is resisted by the pole), and also retains the stability of the vehicle owing to the steering wheels having a very small lateral movement. The axles of the front wheels are provided with horizontal arms by which they are coupled together and can be simultaneously but unequally steered, the correctness of the radiating action thus obtained depending upon the angles which the arms make with the planes of these wheels. The steering is performed by a hand-wheel mounted upon an inclined pillar and acting, by worm gear and a ball jointed rod, upon the arms of the axles of the front wheels. To reduce the steering resistance these axles are inclined downward so as to bring the contact points of the wheels with the road more nearly under the axle pivots.

The lubricators and the tank for petrol are carried on the dash board, and the handles for controlling the ignition and the governor are mounted on the steering pillar, while the accumulators are accommodated in the car body.

The exhaust gases are discharged beneath the frame at the rear, through a silencer consisting of a cylindrical vessel packed with perforated plates.

The frame is built of wood strengthened by steel flitch plates and is attached to the axles by laminated springs; the engine and gear box are, however, carried on a separate frame constructed of channel bars and secured to the main frame. The wheels shown are of the artillery pattern, with wooden spokes held between metal flanges forming the nave, and have wooden felloes provided with steel rims suitable for receiving pneumatic tires. The wheels throughout are 800 mm. (31·5 in.) diam., the wheel base is 2·1 m. (6·9 ft.) and the outside width of the track is 1·25 m. (4·04 ft.). The overall length of the car is 3·35 m. (11 ft.), its width 1·5 m. (5 ft.), and its weight loaded about 1 ton.

This model is so mounted in the case that the driving wheels and mechanism can be rotated by an external handle. The steering wheel can be manipulated by an external hand wheel so that the radiating action of the front axles may be investigated, and the mounting is such that when the front wheels are directed for a curved path the corresponding difference in the motions of the driving wheels results, so that the action of the differential gear can also be observed under various conditions. M.3321.

178. Model of motor car "Silver Ghost." (Scale 1 : 4.) Presented by Messrs. Rolls-Royce, Ltd., 1911. Plate V., No. 1.

This model represents the 40–50 h.p., 6 cylinder, Rolls-Royce car which, in 1907, carried out a 15,000 miles reliability road trial, officially observed by the Royal Automobile Club, during which it ran 14,371 miles without an involuntary stop for other than tire troubles. At the conclusion of the trial, the car was dismantled and examined and all parts, in which the slightest measurable wear could be detected, were replaced at a cost of just over 2*l*.

The car is of the live axle type and has an engine with six cylinders 4·5 in. diam. by 4·5 in. stroke, which develops about 48 h.p. when running at 1,200 r.p.m. The cylinders are cast in two groups of three, the valves being all on one side and operated from a single cam-shaft. The crankshaft is hollow and has a bearing between every two adjacent cranks, with forced lubrication. The crank casing is of aluminium and its lower half can be easily removed for inspection. The explosive mixture is supplied by an automatic carburetter which can be adjusted from the dash-board, and the speed is controlled by a centrifugal governor acting on a throttle valve. Both accumulator and magneto ignition are fitted, each having separate sparking plugs. The cylinders are cooled by jackets into which water is forced by a rotary pump and then sent through a radiator placed in front of the motor; a belt-driven fan is mounted behind the radiator.

The fly-wheel forms one member of a cone clutch which is arranged so that there is no external thrust; the other member of the clutch is connected with the gear-box by a shaft with universal joints. The gear-box has a gate change, four forward speeds and a reverse, and a direct drive is obtained on the third speed. The power is transmitted to the rear axle by a shaft having universal joints at its ends; this shaft drives the two parts of the axle through bevel wheels and a differential gear contained in a central casing. The axle casing is trussed and tied to the frame by radius rods. The axles run in ball bearings, and each driving wheel is fitted with a brake drum and an expanding ring operated by a hand lever; there is also a pedal brake acting on a drum fitted on the driving shaft behind the gear-box. The front axle is a forging of I section having pivoted ends which are fitted with ball thrust bearings.

The frame is of pressed steel, of channel section and of varying depth; it is supported on semi-elliptical springs, those at the back having their rear ends carried by the ends of a transverse spring fixed to a central bracket. The wheels are of the artillery pattern and are fitted with grooved Dunlop pneumatic tires. The front tires are 875 mm. by 105 mm., and the rear tires are 880 mm. by 120 mm. The wheel base is 11·25 ft. and the width of track is 4·66 ft. The car is fitted with a "Roi des Belges" body, and an

adjustable wind screen. The petrol tank is carried beneath the driver's seat, and the accumulators and the acetylene generator for the lamps on the footboard, where two spare tires are also carried.

The car weighs 1·65 tons, unloaded, and about 2 tons with passengers and baggage. During the trial the car averaged 15·7 miles, or 31·08 ton miles, per gallon of petrol. M.3934.

179. Photograph of motor omnibus. Presented by the London General Omnibus Co., Ltd., 1912.

This represents the "B" type of motor omnibus designed for the company in 1910 to comply with the Police Regulation limiting the weight of these vehicles to 3 tons. The type has been so successful that it has been practically adopted as the standard for petrol motor omnibuses (*see* No. 1071).

The omnibus has a 30 h.p. four-cylinder engine, which drives a longitudinal shaft through a three-speed gear-box having silent chain gearing; this shaft drives the live rear axle by means of an overhead worm gear. The frame is of ash flitched with steel plates on both sides, and the wheels are of cast steel with solid rubber tires. The body is made as light as possible and seats 34 persons. M.4037.

180. Holden's motor bicycle, 1897. Presented by Col. Sir H. C. L. Holden, K.C.B., F.R.S., 1910.

The first petrol motor bicycle was patented and constructed by Daimler in 1885, but it was not until about 10 years later that serious attempts were made to produce a practical machine of this type. The bicycle shown, which was patented by Col. Holden in 1896 and 1897, is one of the most noteworthy of these.

The motor has four horizontal air-cooled cylinders 2·125 in. diam. by 4·5 in. stroke, placed two in line at each side and incorporated in the frame, of which they form the lower member. The pistons of each pair of cylinders are in one piece and are directly connected with parallel overhung cranks on the axle of the rear driving wheel, which is 20 in. diam. The pistons always move together, but, the impulses being arranged alternately in one cylinder at each end, there is an impulse at each stroke.

The cylinders are steel tubes, fitted into recesses formed in castings at each end containing the valves, and these castings are tied together by three long bolts. Slots are cut through the cylinders at mid-length to permit the passage of the crosshead pin, which is fixed in the middle of the pistons. The pistons are packed with three spring rings and an asbestos ring. The inlet and exhaust valves are placed one above the other, the former being automatic and the latter operated by rocking levers moved by cams on a longitudinal shaft driven by a chain and worm gearing from the driving axle. Subsidiary pieces on the valve levers are used to keep the exhaust valves open when starting, or for controlling the speed, and these are operated by a hand lever.

The carburetter is of the surface type and consists of a tank containing the petrol, with a vertical longitudinal diaphragm of copper wire gauze, through which the air passes on its way to the mixing valve. The diaphragm, being wet with petrol, forms a large surface from which the air takes up the petrol vapour. The mixing valve is mounted on the head tube of the frame, and in it the rich carburetted air meets the supply of pure air entering through a self-closing valve; the quantity of air is regulated by a piston, the position of which is adjusted by a handle-bar lever. Part of the exhaust gas is passed through a pipe in the petrol tank. The ignition is by an electric spark, a secondary battery and coil being carried behind the seat. The contact-maker is fitted on the driving axle, and a commutator on the camshaft distributes the secondary current to the four sparking plugs; a switch is fitted on the handle-bar. Lubrication is effected by a simple mechanical lubricator, which is a small chain pump, driven from the cam shaft by a belt,

and delivering the oil to the feed pipes. The motor is enclosed by an easily removable sheet-metal casing.

The front wheel of the bicycle is 24 in. diam., and it is geared up from the pedals by crypto gearing; a hand-applied rim brake is fitted to this wheel, and fixed foot-rests are provided. The wheel base is 4 ft. The motor develops about 3 h.p. when running at its maximum speed of 420 rev. per minute, giving a speed of 25 miles an hour. The complete bicycle weighs 123 lb. M.3781.

181. Werner motor bicycle of 2 h.p. Received 1912.

This form of motor bicycle was patented by Messrs. M. and E. Werner in 1901 and 1902, and its principal features have been adopted since by most other makers. The machine has a single cylinder, air cooled engine placed vertically low down in the frame, in front of the ordinary crank bracket and with the crank case forming an integral portion of the frame. A small pulley on the crankshaft drives a large one, fixed to the back wheel, by means of a belt, while the pedals, cranks, and chain are retained for assisting the engine when necessary.

The engine is of the De Dion-Bouton type, with a cylinder 68 mm. (2·68 in.) diam., by 72 mm. (2·84 in.) stroke, and develops about 2 h.p. when running at 1,500 rev. per min. The cylinder head is cast separately and contains the exhaust valve with the automatic inlet valve directly above it. Both cylinder and head are furnished with projecting fins for radiating the heat, and they are held together and to the crank case by two long studs. The aluminium crank chamber supports the crankshaft and entirely encloses a pair of fly-wheels that form the crank webs. A short spindle fixed to the case carries the exhaust valve cam, which is driven by spur gearing from the crankshaft, the gears and cam being enclosed.

A float feed spray carburetter is fitted, and its float acts directly on a valve in the bottom of the chamber. The jet is placed vertically in a horizontal passage through which the air is drawn. A butterfly throttle valve controls the mixture, while a separate cylindrical valve regulates the air supply. The De Dion system of accumulator and coil ignition is employed. In this the low tension current from an accumulator is transformed to a high tension current by means of a non-trembler induction coil through which the current flows only when the primary circuit is closed by a contact maker operated by a cam fitted to the end of the engine cam shaft. The carburetter and ignition controls are fitted on the top tube of the frame, while a cut-out switch is mounted on the handle-bar. A large tank is fitted to the frame above the engine, and this is divided into three compartments, holding the petrol, lubricating oil and the accumulator. The oil tank is fitted with a pump for forcing the oil into the engine crank chamber.

The frame is of the ordinary diamond shape with an extra horizontal tube above the engine, while the front fork is plain. A foot brake is fitted which acts on the inner side of the large belt pulley. As originally made, the drive to the rear wheel was by a flat belt, but the pulleys have been altered to suit the improved V belt; the gear ratio is 7:1. The machine weighs 89 lb.

M.4001.

182. 3½ H.P. motor bicycle with multi-speed gear. Lent by Messrs. Rudge-Whitworth, Ltd., 1915. Plate V., No. 2.

This is a good example of the standard type of single cylinder, belt-driven motor bicycle, but it embodies several special features patented by the makers in 1910 and 1911. The chief of these is the variable speed gear which consists of variable belt pulleys on the engine shaft and rear wheel, the one expanding as the other contracts, so that a gradual change of gear is obtained between the upper and lower limits. A Rudge machine was the first in this capacity to cover over 60 miles in an hour on the Brooklands track, and a Rudge Multi won the Senior Tourist Trophy in 1914.

The engine has a single cylinder, 85 mm. (3·35 in.) diam. by 88 mm. (3·46 in.) stroke; its volume is 499 cc., and it is rated at 3·5 h.p., but it will

develop 7·5 h.p. at 2,000 rev. per min. It is set vertically, and the crank case forms an integral portion of the frame, to which it is securely attached by lugs and bolts. The inlet valve is placed directly over the exhaust valve, and is operated through an overhead lever; both valves are actuated by levers resting on cams mounted on a half speed shaft that is driven from the crankshaft through two intermediate spur wheels. The cam shaft also drives the C.A.V. high tension magneto, which is placed in front of the engine. The cylinder and valve-chambers are air-cooled, and for this purpose have horizontal fins projecting from them, these fins increasing in area towards the cylinder head. The explosive mixture is supplied by a "Senspray" carburetter (*see* No. 465), the air supply and throttle valve being controlled by Bowden wires and hand levers mounted on the right side of the handle-bar. The exhaust gases are led forward to a silencer, which terminates in a long pipe. When starting, the exhaust valve may be lifted by means of an inverted lever on the left handle-bar grip. A lever controlling the magneto is fitted to the left side of the tank.

The crankshaft is extended on the left side, and carries a small V-grooved pulley, with which it is connected by a multiple plate clutch, operated through a Bowden control lever on the left side of the handle-bar. The pulley has an adjustable inner flange, which is moved laterally by a long vertical lever and cam surfaces formed on the engine casing; the upper end of the lever is held by one of twenty notches cut on a bar attached to the petrol tank. A rubber belt 0·875 in. wide drives a large grooved pulley, the inner flange of which is fixed to the rim of the rear wheel; the outer flange of the pulley is mounted on spokes attached to a separate hub shell that slides along the wheel hub, and its lateral position is determined by a central rod and levers connected with the gear lever by other rods. Thus, when the engine pulley flange moves outward to increase its effective diameter, the rear pulley flange moves outward also so as to reduce its diameter, and the belt line remains parallel with the frame. The range of gear obtainable is from 3·5 : 1 to 7 : 1, and when necessary the belt tension can be increased by turning a screw. The engine is started by pedals on a crank axle fitted close behind it, and the chain drives one of the intermediate wheels of the valve timing gear; by this arrangement the chain does not interfere with the removal of the back wheel.

The frame is of general diamond form, with a second horizontal tube above the engine, but the seat pillar meets the back stays below the level of the top tube, so as to give a low position to the saddle. The front wheel is mounted in a spring fork, the trussed fork carrying the wheel being connected with the ball head of the frame by two pairs of links and controlled by an enclosed helical spring in compression. A Bowden brake is fitted to the front wheel, and is operated by an inverted lever on the right handle-bar grip, while a rear wheel brake acts on the front of the driving pulley and is applied by a pedal. Fixed foot-rests are fitted in front of the engine, and the pedals can be placed parallel with one another so as to serve as alternative rests. The handle-bars are completely covered with celluloid, as are also the wheel hubs. The luggage carrier and rear mudguard are combined, and the end of the latter, which also forms a number plate, is hinged so that it can be turned up when removing the back wheel, an operation which only necessitates the removal of the belt and the two spindle nuts. Leather tool cases are suspended from the carrier, and are protected on the under and inner sides by steel plates. The back wheel is fitted with a spring stand that automatically picks up when the machine moves forward. The front wheel is fitted with a stand, which also serves as a mudguard stay.

The petrol tank has a capacity of 2 gal., and is fitted between the top tubes of the frame; all its fittings are on one side so as to facilitate its removal, and a passage is formed through the tank, over the valves, to permit them to be ground in without removing the cylinder or tank. The lubricating oil tank holds 0·5 gal., and is fitted behind the seat tube; a pump, worked by a pedal, is fitted in the tank for forcing the oil into the crank case. The tires are 650 mm. by 65 mm., three-ribbed, beaded edge, Dunlops. The machine has a wheel base of 55 in., and it weighs 214 lb.

183. Wall auto-wheel. Lent by Messrs. Auto-Wheels, Ltd., 1914.

This auxiliary motor-driven wheel, for attachment to a pedal-driven bicycle, was patented by Mr. A. W. Wall in 1908, and subsequently improved by the makers.

It consists of a 1 h.p. single cylinder air-cooled petrol motor, having a bore and stroke of 2·125 in., mounted on a frame which is attached to the bicycle, on the off side of the rear wheel, by a horizontal transverse pivot about which it is free to turn. The driving wheel can thus rise and fall according to the road surface, and does not interfere with the steering of the bicycle. The weight of the auto-wheel alone gives sufficient adhesion for driving. The engine has an automatic inlet valve and a mechanically operated exhaust valve, but the latter may be lifted when starting, to reduce the compression. The cam shaft runs at one-fourth the speed of the crank-shaft, the valve cam being double; this shaft is utilised to transmit the power to the wheel, which it does by means of a chain, the total speed reduction being 8 : 1. The engine cylinder is mounted on a crank casing which is extended to form the magneto bed, oil tank and silencer. An outside fly-wheel is fitted, and the engine is attached by lugs to a tubular frame carrying the driving wheel, which is 20 in. diam., and fitted with a 1·75 in. pneumatic tire. The petrol tank is mounted on top of the frame, while a simple automatic carburetter and a "U.H." magneto are fitted. The engine is controlled by a single handle-bar lever through Bowden wires connected with the throttle and valve lifter. The pivot is fixed to two tubes which are connected with the bicycle frame at three points; a hinged stand is also provided at the end of the pivot. The petrol tank holds 0·5 gal., which quantity serves for over 50 miles' running; a pint of lubricating oil suffices for 600 miles. The wheel will propel a bicycle, on the level, at from 6 to 20 miles an hour, and will average 16 miles an hour on ordinary roads. It weighs about 40 lb. The example shown is attached to a "Swift" bicycle. Inv. 1914–666.

LOCOMOTIVES.—II.

For Railways, etc.

In this section are grouped the engines employed in moving vehicles on special tracks, such as railways and tram lines, by the agency of other than animal power; the different forms of track and of vehicles used upon them are placed in the sections devoted to land transport (*see* p. 358 *et seq.*).

The rigid and confined track, as a means of lessening resistance with animal haulage, had been in course of gradual evolution for about 200 years before the use of mechanical motors upon it was attempted; since then both have developed concurrently.

Richard Trevithick, and his cousin Andrew Vivian, in 1802 patented a high-pressure steam road carriage which, by some modifications, Trevithick in 1804, adapted for working on a plateway. With one of these engines he succeeded in hauling a load of 25 tons on a line between Merthyr Tydvil and Abercynon, but owing to the weakness of the track the engine failed from the economic point of view, the damage done to the plates rendering it a more expensive agent than animal power; it had, however, smooth wheels, and discharged its steam into the chimney; the effect upon the fire of this method of exhausting the steam was appreciated at the time. In 1808

Trevithick exhibited near what is now Euston Square, London, a steam locomotive weighing 10 tons which ran on a circular railway at a speed of 12 miles an hour, and the public were permitted to try the new mode of travel upon payment; again the experiment failed financially through the weakness of the rails. Trevithick appears, however, to have made several similar tram engines for lines in various mining districts (*see* Nos. 184 and 185).

In spite of the fact that the adhesion of smooth wheels on rails had been demonstrated to be sufficient for a locomotive on certain tracks, the idea that something more was necessary was generally held, probably owing to the weakness of the plate-ways restricting the weight allowable per wheel to an amount that was frequently seen to give insufficient grip. To avoid this difficulty John Blenkinsop, in 1811, patented a form of rack railway (*see* No. 186), which was laid between Middleton and Leeds in 1812, and between Kenton, Coxlodge and the Tyne in 1813. The engines employed were made by Messrs. Fenton, Murray and Wood, and appear to have been the first commercially successful locomotives ; they had two double-acting cylinders, instead of a single cylinder and fly-wheel as generally used by Trevithick, and, although the boilers had only single flues, these engines remained in use till 1835. In 1812 Messrs. W. & E. W. Chapman patented another form of locomotive in which simple adhesion was discarded, the machine propelling itself by toothed wheels gearing on the upper side with a long chain secured to the ends of the line; this was tried in 1813 at Heaton Colliery, but was soon abandoned.

In 1813 William Hedley, assisted by Christopher Blackett, the proprietor of Wylam Colliery, confirmed Trevithick's results as to the possibility of obtaining sufficient grip by adhesion, and, after some experimenting, constructed a locomotive with smooth wheels coupled together by gearing (*see* No. 188). The motor portion was an adaptation of the then established form of stationary engine, with vertical cylinders, tappet valve gear, and rocking beams as introduced by Newcomen and retained by Watt.

In 1814 George Stephenson constructed for the Killingworth Colliery his first locomotive, named "Blucher," which was a geared engine exhibiting no improvement on the work of his predecessors. In his second engine, however, he reintroduced the direct action of the connecting rods on the driving-wheels, as applied by Trevithick in 1808, and used coupling rods for connecting the wheels, although these were subsequently discarded for chain gearing. In this way a successful type of colliery locomotive was arrived at, and one which slowly proved its superiority to traction by animals where heavy loads were to be moved at a slow pace.

In 1825 the Stockton and Darlington Railway was opened for public traffic, the only engine on the line being, however, "Locomotion" (*see* No. 190). Although intended solely for the conveyance of minerals and goods, the financial success of this, the first public steam railway in the world, was considerably

increased by the rapid development of passenger traffic. Other engines were soon required for the line, and in 1826 Messrs. Wilson & Co. built one embodying the use of four vertical cylinders, each pair working directly on to two cranks at right angles on a single axle; this improved feature, but with only a pair of cylinders, was retained by Timothy Hackworth when the engine was rebuilt in 1827 (*see* No. 191). In 1826 also Stephenson produced the "Experiment," a locomotive with two cylinders working directly on to one axle, and inclining downward, so making another advance towards the now almost universal arrangement of the engine.

The locomotive had not as yet exceeded the speed of the stage coach, while its noise, smoke and jerky motion were defects that rendered it by no means popular, even with the unprejudiced; so much was this the case that in 1829, when the Liverpool and Manchester Railway was under construction, the directors were still undecided as to the best means of haulage. They offered accordingly a prize of 500*l.* in order to find the best locomotive available and thus be able to compare the new method with horse traction. The results attained by the "Rocket" (*see* Nos. 193 and 194) were such as to settle the question immediately in favour of steam locomotives; this historical engine was moreover the first conveyance that travelled faster than a race-horse, and thus foreshadowed the great future of the railway system.

Between 1830–5 the development of the steam locomotive in size and detail was most rapid; the "Northumbrian" of 1830 had a complete smokebox, and the "Planet" of the same year had inside cylinders at the front end working directly on to a double-cranked rear-driving axle; engines with four and six wheels connected by external coupling rods had been in use since 1826, but the whole arrangement of the locomotive now rapidly settled into the almost universal form, as will be seen in the series of drawings Nos. 201, 204, and 205. The introduction about this period, of improved valve gears led gradually to a reduction in the fuel consumption, but the full advantage of expansive working was not realised till the invention by Howe, in 1842, of the link motion (*see* No. 273) which rendered such working both simple and convenient.

The earliest attempt to arrange a locomotive as a compound engine was made about 1849, on the Eastern Counties Railway, when an ordinary goods engine had its valves so altered that the first cylinder cut off at about half stroke and then allowed its steam to expand in both cylinders. In 1876 Mons. A. Mallet introduced compounding on the Bayonne and Biarritz Railway, using one high and one low-pressure cylinder, which could, however, be worked simple if necessary. Mr. F. W. Webb commenced his work in compounding in 1878, by reducing the diameter of one of the cylinders of an ordinary engine and letting its exhaust pass into the other, while in 1881–2 he built the "Experiment" with two outside high-pressure cylinders driving the hind wheels and one low-pressure inside cylinder driving the front axle, there being no coupling rods (*see* No. 237). In

1897 he introduced his last type in which four cylinders were used owing to the perfect balancing thus attainable, coupling rods being, however, retained. Mr. A. von Borries built in 1880 some engines on the two cylinder compound principle for the Hanoverian State Railways, and in 1885 Mr. T. W. Worsdell adopted the same arrangement on the Great Eastern Railway and subsequently on the North Eastern Railway (*see* No. 238); as the cylinders are side by side between the frames, the arrangement is one to which existing engines can be easily altered. In 1885 M. de Glehn introduced his four cylinder compound engine having two inside high-pressure cylinders driving one axle and two outside low-pressure cylinders driving a separate axle. M. du Bousquet modified this arrangement by interchanging the high and low-pressure cylinders and coupling the driving axles, thus originating the form now so much used on the Continent. In the system patented in 1889 by Mr. S. M. Vauclain of the Baldwin Works, U.S.A., and extensively adopted, there is a high-pressure cylinder and a low-pressure one beneath it, outside the frames on each side; the adjacent piston-rods are secured to a single crosshead, so that additional mechanism is dispensed with (*see* No. 242). In 1898, Mr. W. M. Smith introduced his three cylinder system with one high-pressure inside cylinder and two low-pressure outside cylinders, all driving the same crank-shaft; this has been used on the North Eastern and Midland Railways. Compounding, however, has not been greatly favoured on British railways. Similar advantages are more simply obtained by the use of superheated steam and piston-valves. The high degree fire tube superheater, patented by Dr. W. Schmidt in 1900, is that most used, but some success has also been attained by the low degree smoke box type (*see* No. 262).

For working exceptionally steep inclines on ordinary railways the centre rail system, first proposed in 1830, has been tried (*see* No. 251), but such inclines are usually worked by locomotives having eight or ten coupled wheels of small diameter. On mountain railways, however, the gradients are such that the cable haulage or the rack system must be adopted. The central ladder rack was first used in 1852 and subsequently developed by Mr. N. Riggenbach (*see* No. 252). The improved form of rack cut from flat bars, which has been used on many recent lines, was patented by Mr. R. Abt in 1882 (*see* No. 253). Some of these rack lines are worked by electric locomotives.

Steam locomotives for tramways have been extensively used, sometimes assisted by reservoirs of compressed air; but now for all purposes requiring light trains at short intervals electric motors have been generally resorted to. The absence of waste gases gives the electric motor an overwhelming advantage where tunnels are general, while the actual efficiency of large steam engines, as employed at electricity generating stations, combined with the general high efficiency of the dynamo, compensate for the losses resulting from the indirect way in which the energy derived from the coal consumed is applied to the train when propelled by electric motors.

184. Original drawing of a Trevithick tram engine. (Scale 1 : 12.) Photographs of a model of Trevithick's first tram engine. Presented by F. W. Webb, Esq., 1893.

Trevithick was building some of his high-pressure engines at the Pen-y-darran Iron Works, near Merthyr Tydvil in 1803, when, at the suggestion of the proprietor, Mr. Samuel Homfray, he undertook to construct a steam locomotive to haul trucks on the tramway from the works to Navigation House, near Abercynon, a distance of about 9 miles. The engine was completed and tried in 1804, with the result that, when hauling five wagons and a useful load of 13 tons, its speed was about 5 miles an hour, with a coal consumption of about 25 lb. per mile. Owing, however, to the frequent breakages of the cast iron tram plates, the locomotive was soon stopped and used for stationary purposes in the ironworks.

The photographs shown were taken from a full sized reproduction of this engine, and a portion of the plateway, made by Mr. Webb, at Crewe, in 1893, as representing the first engine that ran on a confined track by the force of high-pressure steam and relied solely upon the adhesion of smooth wheels.

The locomotive had a single horizontal cylinder 8·25 in. diam., by 54 in. stroke, enclosed in the boiler, which was of cast iron, 6 ft. long by 4·25 ft. diam., with a wrought iron furnace flue. The piston-rod crosshead was controlled by round guide-bars, and from it passed two return connecting rods to the cranks on the flywheel shaft, on which was a spur wheel gearing into a large intermediate spur wheel carried by a stud on the side of the boiler; this wheel geared into a spur wheel on each of the two travelling axles, so that the adhesion due to the total weight of the engine was available for traction. The travelling wheels were 45 in. diam., and revolved at practically the same speed as the crankshaft, so that the tractive effort per pound of mean steam pressure in the cylinder was about 40 lb. The valve arrangement consisted of a four-way cock similar to that shown in No. 161, and worked by a tappet rod from the crosshead; the exhaust was delivered into the chimney, where it was noticed that the waste heat rendered it invisible, and that it made the draught much stronger.

This engine weighed in working order 5 tons, so when Trevithick found it could deal with a load of 25 tons he considered it was unnecessarily powerful for the line, and therefore decided to build a smaller one, probably to this earlier design, which is identical with it in arrangement, but has a cylinder 4·75 in. diam. by 36 in. stroke, and a tractive factor of 11; there is, however, no evidence that the lighter engine was ever constructed. M.2553.

185. Original drawings of Trevithick's Newcastle railway locomotive. (Scales 1 : 16, 1 : 12, and 1 : 2.) Presented by Thomas Smith, Esq., 1873.

It appears that Trevithick visited Newcastle in 1804 and arranged with John Whinfield, of Gateshead, for the manufacture of his locomotives in that district. Some of the drawings shown are dated 1804, and in May 1805, an engine for Mr. Blackett, of Wylam, was completed; this was probably that shown in the shaded drawing in which the wagon way has wooden rails and a gauge of 5 ft., as in use at Wylam till 1808. The arrangement of the engine is almost identical with that in the South Wales engine (*see* No. 184); the cylinder is 9 in. diam. by 36 in. stroke, and the boiler 4 ft. diam. by 6·6 ft. long; the road wheels are 38 in. diam., but only revolve at four-fifths of the speed of the crankshaft, so that the tractive factor was 48.

The rougher working drawings are probably from Trevithick's own hand, and amongst other details they show the "Regulating and throttle cocks for the engine." These two plug valves were combined in a single casing, in which the smaller plug served as a regulator for stopping the engine or controlling its speed, while the larger four-way plug was oscillated by a tappet gear so as to place the ends of the cylinder alternately in communication with the steam and exhaust connections, as now done by a slide valve. This

locomotive was probably the first one with flanged wheels; it appears, however, to have been only a partial success, probably owing to the wooden rails being unequal to carrying its weight, which was about 4·5 tons. M.1310.

186. Model of Blenkinsop locomotive (working). (Scale 1 : 8.) Made in the Museum, 1910.

This model represents one of the four engines built by Messrs. Fenton, Murray, and Wood, in 1812–13, to work in conjunction with the rack railway patented by John Blenkinsop in 1811, and laid at that time between Leeds and the Middleton Colliery, a distance of 3·5 miles. This enterprise was the first in which the steam locomotive was used with financially successful results; the engines remained at work for about 20 years. It is recorded that similar engines were used also on three other colliery railways. The rack railway has, moreover, survived, and is extensively adopted for mountain lines with exceptionally steep gradients.

The arrangement of the engine was an improvement on those built by Trevithick, although obviously based on them, in having, at the suggestion of Matthew Murray, two cylinders working on separate shafts so connected that the cranks remained at right angles, thus avoiding any difficulty in starting. There is reason to believe, however, from the contemporary records upon which this model is based, that the design did not arrive at once at its final shape.

The engine had a cast-iron boiler of oval section 37 in. by 32 in. and 9·6 ft. long, made in two parts bolted together, and having a single furnace flue 14in. diam passing through it; in the boiler on the centre line were sunk, for one half their length, two vertical cylinders, 9 in. diam by 22 in. stroke, exhausting directly into the atmosphere. Each piston-rod was controlled by two vertical guides, while by a pair of return connecting rods it drove parallel outside cranks on a crankshaft below it. These two crankshafts were connected through gearing with an intermediate shaft, upon one end of which was a large spur wheel gearing with the teeth of the rack rails. The steam distributing valves were four-way plug cocks oscillated through 90 deg. by wrist plates which were connected, by horizontal rods above the boiler, with vertical levers pivoted near the centres of the boiler ends; these levers extended an equal distance downwards, and their lower ends were connected with eccentrics mounted on the crankshafts. Reversing was effected by making the cocks oscillate through an angle of 90 deg. adjacent to the angle used for forward motion, and this was done by attaching the valve rods to points in the wrist plates at right angles to the former ones. Short levers, having the valve rods attached to their lower ends, were mounted loosely on the valve stems, and pins in their upper ends engaged with either of two holes in the wrist plates. Forked hand-levers, engaging with collars on the valve lever bosses, were provided for sliding them into and out of gear. Two smaller plug cocks, coupled by a rod, controlled the steam supply from the boiler. A direct loaded spring safety valve was fitted at each end of the boiler shell. The boiler and gearing were supported by a wooden frame carried upon four wheels 35 in. diam., with a wheel base of 7:33 ft.; the driving spur wheel was 38·2 in. pitch diam., and revolved at one half the speed of the crankshafts, so that the tractive factor was 93·6. The boiler was fed by a pump, immersed in a water tank carried at the front end of the engine, and driven by the valve gear. The fuel was carried on a platform between the frame beams, at the rear of which the driver stood, so that no tender was required. The boiler and cylinders were lagged entirely with wood.

Blenkinsop stated that one of these engines weighed 5 tons, and cost 400*l*., and that it did the work of 16 horses in 12 hours. It drew 27 wagons, representing a load of 94 tons, at 3·5 miles an hour on the level, or 15 tons up a gradient of 1 in 18; lightly loaded its speed was 10 miles an hour. The consumption of coal was 21·3 lb., and of water 14·3 gal. per train mile, so that each pound of coal evaporated 6·7 lb. of water.

The track consisted of cast iron edge rails each 3 ft. long. On one side of the track the rails had cast with them six teeth of 6 in. pitch projecting from their outer sides. The rails were held in special chairs by wooden keys, while the chairs were spiked to wooden cross sleepers (*see* No. 818). The gauge of the rails was 4·12 ft. M.3767.

187. Hedley's experimental model for testing adhesion. Presented by Thomas Hedley, Esq., 1862.

Christopher Blackett, the proprietor of Wylam Colliery, had since 1804 been in search of some means of haulage better than animal power for conveying coal wagons over the 5 miles of track between his colliery and the wharves on the Tyne. He had found that Trevithick's locomotive did not succeed on his wooden rails, and, the then generally accepted explanation being that the smooth wheels gave insufficient grip, no further experiments were made in mechanical traction till 1812. In that year William Hedley, the viewer of Wylam, constructed the model shown, which has four road-wheels secured to two axles geared together by intermediate spur wheels, and capable of being rotated by external winch handles.

The results he obtained from the model led to the construction of a full-sized under-frame, with wheels similarly connected by gearing, and worked by men carried on it, so that the adhesion of all of the coupled wheels was available for tractive effort; this frame was subsequently fitted with a cast-iron boiler and a single steam cylinder 6 in. diam., which drove the road-wheels through intermediate gearing. After repeated trials with this experimental engine the construction of an entirely new one was decided upon, chiefly because of the defective steaming capacity of the boiler. M.340A.

188. "Puffing Billy" locomotive. Received 1865. Plate V., No. 3.

This engine was constructed at Wylam Colliery in 1813 by William Hedley, assisted by the enginewrights, one of whom, Timothy Hackworth, subsequently became locomotive superintendent of the Stockton and Darlington Railway. It worked between the colliery and the staithes at Lemington-on-Tyne.

The engine has two vertical steam-jacketed cylinders 9 in. diam. by 36 in. stroke, which, by grasshopper beams, transmit the power downward by connecting rods to a shaft with overhanging cranks set at right angles. This shaft carries a spur wheel, which, by four other spur wheels, transmits the power to the four driving-wheels, each 39 in. diam., giving a tractive factor of 40, although originally the gearing made this factor 80. Steam is distributed by slide valves worked by a tappet motion, and the places for the driver and fireman are at opposite ends of the boiler.

The boiler is a wrought iron cylinder with one egg end, and has an internal return furnace flue, as used by Trevithick; the grate area is 6 sq. ft., the heating surface 77 sq. ft., and the steam pressure was 50 lb. per sq. in. The engine weighed 8·3 tons in working order, and usually hauled about 50 tons at a speed of 5 miles an hour. The tender consists of a wooden frame, supported on four wheels, carrying a water tank and coal box; it weighed 4·3 tons when loaded.

Owing to the weakness of the plate-way, which was of cast iron (*see* No. 817), the engine was in 1815 rebuilt as an eight-wheeler, each group of four wheels being carried in a kind of bogie, and two more wheels introduced into the gearing. It was altered back to four wheels about 1830 when the line was relaid with the cast iron edge rails now seen under it. These rails are of the double-flanged fish-bellied type, with half-lap joints supported in chairs spiked to cross sleepers, and with a gauge of 5 ft.; each rail is 4 ft. long, and weighs 52 lb.

The adjacent photographs show this engine at work in 1862, prior to its removal to South Kensington; also the sister engine, "Wylam Dilly," which worked till 1867, and is now preserved at the Edinburgh Museum of Science and Art. When first introduced the noise and smoke from these locomotives caused considerable irritation, so that legal opinion was taken on the subject (*see* adjacent frames), but the nuisance was subsequently abated by passing the exhaust steam into a quieting chamber before discharging it into the chimney. M.340.

189. Drawings of early locomotives employed on the Stockton and Darlington Railway, 1825–62. (Scale 1 : 24.) Prepared from tracings and particulars presented by C. E. Stretton, Esq., 1901.

The Stockton and Darlington—the first public steam railway in the world—was originally projected in 1817 by Edward Pease of Darlington, chiefly for the conveyance of coal from the Bishop Auckland collieries to the sea-board. The Bill authorising its construction, after being twice rejected, was passed in 1821; it provided for its being worked "by men and horses, or otherwise." In 1822 the line was re-surveyed and construction commenced; but in the following year, at the advice of George Stephenson, who made the final survey and had been appointed the engineer, a fresh Act was obtained, giving power to carry passengers as well as goods, and to employ locomotive engines.

The line commenced on the north bank of the Tees at Stockton, and proceeded in a westerly direction to Darlington and thence to the north-west terminus at Bishop Auckland, a distance of 24·66 miles; but there were four branches which brought up the total length to 36·25 miles, as shown on an adjacent ordnance map. The line was single, with passing places every quarter-mile; wrought iron fish-bellied rails weighing 28 lb. per yard were used, and the gauge was 4 ft. 8 in.; but more clearance being required, this was increased by 0·25 in. in 1840, and soon afterwards to the present standard. The cost per mile was about £9,000, and the ruling gradient was 1 in 104, but at Brusselton and Etherley there were inclines of nearly 1 in 33 which were worked by stationary engines.

The first rail was laid at Stockton in May, 1822, and the line was opened for traffic in September, 1825, by the engine "Locomotion," driven by George Stephenson and drawing a train of thirty-four vehicles forming a gross load of over ninety tons. The first regular passenger coach, the "Experiment," was put on in October, 1825, from which time both goods and passenger traffic rapidly increased; the identity of the undertaking became lost in 1863, owing to its being absorbed into the North Eastern Railway system. Reproductions of an advertisement and of a way-bill of the original line are shown in an adjacent section.

In the drawing the following ten of the early engines employed are represented, while a table gives particulars of their dimensions:—

No. 1, "Locomotion," was built in 1825 by Messrs. R. Stephenson and Co. This engine is fully described in connection with its model, No. 190; three similar engines, named "Hope," "Black Diamond" and "Diligence," were constructed for this line in 1826.

No. 5, "Stockton," built by Messrs. R. Wilson and Co. of Newcastle in 1826, had four vertical cylinders 6 in. diam. by 18 in. stroke with crossheads sliding in guides and each working, by a return connecting rod, a driving wheel 48 in. diam., thus having a tractive factor of 27. The crank-pins on each axle were at right angles, and each cylinder had its own valve gear and blast pipe; the boiler was 13 ft. long by 4·33 ft. diam. and had a single flue. This engine was unsatisfactory and, having been damaged in collision, portions of it were used in building the "Royal George" (*see* No. 191).

No. 6, "Experiment," built by Messrs. R. Stephenson and Co. in 1826, had inclined outside cylinders, 9 in. diam. by 24 in. stroke, acting directly on six coupled wheels 48 in. diam., thus having a tractive factor of 40. The boiler, 10 ft. long by 4 ft. diam., contained two through tubes 18 in

diam. each with its own grate; the exhaust was conveyed to the chimney by two blast pipes.

No. 5, re-named "Royal George." This engine was constructed at Shildon Works in 1827 by T. Hackworth, who utilised the boiler, funnel and wheels of the "Stockton," but provided two new vertical cylinders with valve motions, and an additional pair of driving wheels. Further particulars of this engine are given in connection with its model, No. 191.

No. 9, "Globe," designed by T. Hackworth and built by Messrs. R. Stephenson and Co. in 1830, had horizontal inside cylinders, 11 in. diam. by 16 in. stroke, placed under the furnace, and four coupled driving wheels 60 in. diam., thus having a tractive factor of 32. The boiler was 10 ft. long by 3 ft. diam. and had a single flue with the grate in one end; on the top of the shell was a copper steam vessel in the form of a globe, from which the engine received its name. This locomotive ran till 1839, when its boiler exploded.

No. 13, "Coronation," designed by T. Hackworth and built by Messrs. R. and W. Hawthorn in 1831, was one of thirteen engines built for mineral traffic; it had two vertical cylinders, 14·5 in. diam. by 16 in. stroke, overhanging at the front and driving, through an intermediate shaft, six coupled wheels 48 in. diam., thus having a tractive factor of 70. The boiler was 13 ft. long by 43 in. diam., and had one furnace tube 9 ft. long and 106 small tubes 4 ft. long.

No. 26, "Swift," designed by T. Hackworth and built by Messrs. R. and W. Hawthorn in 1836, had two vertical cylinders 11 in. diam. by 16 in. stroke working, through an intermediate shaft, the driving wheels, which were 48 in. diam., thus having a tractive factor of 40. The boiler was 9·6 ft. long and of oval section, 3 ft. wide by 4 ft. high; it contained a fire tube 4·6 ft. long, 29 in. diam., and 102 tubes 5 ft. long; its total heating surface was 256 sq. ft.

No. 27, "Arrow," built by T. Hackworth at Shildon in 1837, had inside cylinders 22 in. diam. by 9 in. stroke which, by rocking levers, drove cranks of 18 in. throw in the driving axle. The pair of driving wheels were 60 in. diam., giving a tractive factor of 72, and there were four other wheels 36 in. diam. The boiler had a rectangular firebox of copper, and there were 133 tubes.

No. 43, "Sunbeam," designed by T. Hackworth and built by Messrs. R. and W. Hawthorn in 1837, was a four-wheeled engine with single drivers 60 in. diam. and horizontal inside cylinders 12 in. diam. by 18 in. stroke, giving a tractive factor of 43. It remained in use on passenger traffic till 1856.

No. 165, "Keswick," built by Messrs. R. Stephenson and Co. in 1862, was a large passenger engine with a leading bogie and four coupled wheels 84·5 in. diam.; the cylinders were outside and 16 in. diam. by 24 in. stroke, thus giving a tractive factor of 73. The boiler had 1,053 sq. ft. of heating surface, 12·75 sq. ft. of grate area, and there was a feed-water heating tank under the footplate. M.3089.

190. Model of "Locomotion," engine No. 1 of the Stockton and Darlington Railway. (Scale 1 : 8.) Presented by Sir David Dale, Bart., 1896. Plate V., No. 4.

The engine represented was built by Messrs. R. Stephenson and Co. in 1825, and ceased running in 1846, but is still preserved in working condition at Darlington by the North Eastern Railway Co. (*see* photograph).

The engine has two vertical cylinders 10 in. diam. by 24 in. stroke, each driving by side connecting rods a pair of 48 in. diam. driving wheels. These wheels are of cast iron and are coupled together by external rods that maintain the driving crank-pins of the front and rear wheels at right angles, The valves are of the ordinary type, driven by rocking shafts which both receive their motion from a single eccentric on the leading axle, one shaft being rocked directly, and the other through a bell-crank lever. A platform runs

along each side of the boiler, and from one of these the driver has control of the valve rods, for disengaging and reversing. The tractive power of this engine per lb. of mean pressure in the cylinders was 50 lb., but the boiler pressure used was only 25 lb. per sq. in. The exhaust steam from both cylinders was conveyed by two blast pipes into the chimney. The feed water was forced into the boiler by a single feed-pump 4 in. diam., driven by a lever from the front crosshead.

The boiler is 10 ft. long by 4 ft. diam., and has a single through flue 24 in. diam. and 10 ft. in length, delivering into the chimney, which is 17·5 in. diam., the heating surface is about 60 sq. ft. The wheel base of the engine is 5·33 ft., and the weight in working order is 6·5 tons. A single safety valve is provided, loaded by a weighted lever.

The tender is built of timber, holds 15 cwt. of coal, and carries an iron tank containing 240 gal. of water. The tender, which also acts as a platform for the fireman, is carried on four cast iron wheels 30 in. diam., has a wheel base of 4·75 ft., and when empty weighs 2·25 tons.

"Locomotion" is estimated to have been of about 20 h.p., and had a speed of eight miles an hour. The total weight of engine and tender in working order was about 10·5 tons.

The model is shown supported upon a model of the first railway bridge constructed by George Stephenson; it was erected at West Auckland in 1824, and was only replaced in 1901. The rails are of wrought iron, rolled to the fish-belly form and supported in chairs, which are shown resting on the timber flooring of the bridge. M.2955.

An adjacent photograph shows "Locomotion" standing beside a North Eastern Railway goods locomotive of 1909. M.3825.

191. Original model of the locomotive "Royal George" (1827). (Scale 1 : 16.) Received 1898.

The "Stockton" was No. 5 locomotive on the Stockton and Darlington Railway, and was built in 1826 (*see* No. 189). The engine, however, proved so unsatisfactory that in 1827 Timothy Hackworth, the locomotive superintendent of the railway, obtained permission to rebuild it, and this model represents the reconstructed engine known as the "Royal George," which worked on the line from 1827 till 1842. The model shown was probably made to prove to the directors of the Stockton and Darlington Railway the soundness of Hackworth's design for the reconstruction of their original No. 5 engine.

Using the original boiler shell, which was 4·33 ft. diam. by 13 ft. long, Hackworth increased the heating surface by introducing into it the return flue of Trevithick (*see* No. 184), and as seen in Hedley's "Puffing Billy" (*see* No. 188); the wheels he increased to six in number, all coupled, while he used only two cylinders, 11 in. diam. by 20 in. stroke, arranged vertically over the trailing wheels. The load on the other wheels was distributed by long plate springs arranged as equalising levers.

The piston rods are guided by parallel motions, by the levers of which a valve shaft is continuously rotated; on this shaft are two loose eccentrics that form a valve motion and reversing gear.

The tractive power per lb. of mean steam pressure was 50 lb., and the weight of the engine and tender was 15 tons; it could draw on the level thirty-two coal wagons weighing 130 tons at a speed of 5 miles an hour.

This engine and Stephenson's "Experiment" of 1826 were the first six-wheeled coupled engines ever built. M.3040.

192. The "Agenoria" locomotive (1829.) Presented by W. O. Foster, Esq., 1884.

This engine was built by Messrs. Foster, Rastrick & Co. of Stourbridge for the Shutt End colliery railway at Kingswinford, Staffordshire, which it opened in June, 1829, and afterwards worked over for more than thirty-five

years; it is almost identical with the "Stourbridge Lion," built by the same firm in 1828, and sent to America, where it was the first locomotive to run upon rails on that continent.

The engine has four coupled wheels, 48·75 in. diam., with a wheel base of 5·08 ft., and two vertical cylinders 8·5 in. diam. by 36 in. stroke, driving outside crankpins set at right angles to one another and fixed in the rear wheels; the tractive factor is 53·4. The crossheads are guided by grasshopper parallel motions, and the connecting rods are attached to intermediate points of the beams directly in front of the cylinders, thus reducing the crank throw to 27 in. The slide valves, of the common flat type, are driven by loose eccentrics whose motion is controlled by stops, fixed to the axle, which retain them in the correct positions for forward or backward motion; hand gear is provided for working the valves when reversing, and until the eccentrics attain their positions against the stops.

The boiler consists of a cylindrical barrel 4 ft. diam. and 10 ft. long formed with dished ends. The grate is contained in a furnace tube 29 in. diam., which branches into two flues, each 18 in. diam., through which the heated gases pass to a chamber at the forward end; this chamber is completely within the shell and it communicates with the chimney by a short vertical tube passing through the upper part of the barrel. The back end plate carries the furnace and flues and is attached to the barrel by bolts, thus enabling the whole of the internal portion of the boiler to be easily removed for cleaning or repairs. The boiler is fitted with a dome surmounted by a spring-loaded safety valve and was originally provided, in addition, with a "lock-up" safety valve; a single feed pump is provided which is driven from one of the grasshopper beams. The exhaust steam is turned into the chimney, but, from the exceptional height of the latter, it is probable that this blast was not utilised to increase the draught; at the time the engine was built, great objections were raised to the noise of locomotives, and also to the smoke given off; these annoyances would be reduced by a quiet exhaust and a tall chimney. The grate area is 8·5 sq. ft., and the heating surface about 85 sq. ft.

The engine frames are of wood flitched with iron plates, which form also the axlebox guides; the boiler is secured to the frames at each end, while the cylinders and gear are fixed solely to the boiler. Springs are fitted to the front axleboxes only, as the action of the vertical connecting rods would have prevented their use over the rear axle; the axleboxes were provided with mechanical lubricators, driven by toothed rings on the axles. The wheels are of cast iron with wrought iron tires, and the trailing pair are fitted with balance weights. The engine and tender in working order weighed 11 tons.

The engine is standing on some of the rails and chairs from the Shutt End line (*see* No. 823). M.1620.

193. The "Rocket" locomotive (1829). Presented by Messrs. Thompson and Sons, 1862. Plate V., No. 6.

This celebrated engine was constructed by Messrs. R. Stephenson & Co. in 1829, to compete for the 500*l.* prize offered by the directors of the Liverpool and Manchester Railway to the makers of the most successful locomotive competing at a trial to be held at Rainhill in October of that year; the particulars and conditions of the trial are given in No. 199.

The "Rocket" left Newcastle on September 12th, 1829, going part of the way by canal, and was delivered by wagon at Rainhill on October 2nd; the competition commenced on October 6th and continued for eight days. At that time the "Rocket" was painted yellow, relieved with black, while the chimney was white. Her greatest speed was 29 miles an hour; some years afterwards, however, she ran four miles in 4·5 minutes, or at the rate of 53 miles an hour. After the trial the "Rocket" was purchased by the Liverpool and Manchester Railway Co., and worked on the cutting between Chat Moss and Salford till the opening of the line on September 15th, 1830; during this period, however, the engine was improved by the addition of a smokebox and the chimney was shortened. At the ceremony of opening the

railway, this engine ran over and fatally injured the Right Hon. William Huskisson, then M.P. for Liverpool; this sad accident, however, drew great attention to the possibilities of travelling by steam, as George Stephenson took the injured gentleman to his destination, 11 miles away, at a speed of 36 miles an hour. The "Rocket" worked on the Liverpool and Manchester line till 1837, when it was removed to the Midgeholme Railway, near Carlisle, where it ceased running in 1844; it was brought to South Kensington in 1862.

The engine as it now exists differs in several respects from its form in 1829: the present steam and exhaust pipes, the chimney and the dummy wooden connecting rods were fitted in 1862; the cylinders were originally arranged at an inclination of 37 deg. with the horizontal, but they were altered within a year or two to their present inclination of 8 deg.; the present trailing wheels are quite modern, for the original ones, which were also of cast iron, were 34 in. diam., a size that the higher position of the cylinders rendered admissible.

The engine has two cylinders, 8 in. diam. by 17 in. stroke, directly acting on driving wheels 56 in. diam., thus having a tractive power of 19·4 lb. per lb. of mean steam pressure. The slide valves are worked by loose eccentrics, and there is a clutch arrangement, worked by a treadle, by which these eccentrics could be thrown out of gear when the engine was to be reversed, the valves at the time being independently worked by hand levers. The boiler has a cylindrical barrel 3 ft. 4 in. diam. by 6 ft. long, which was traversed by twenty-five copper tubes 3 in. diam. The firebox was of copper, and was bolted on to the end of the barrel; it had at the top, back, and sides a 2·5 in. water space, while there was a firebrick lining in front. The gases from the firebox passed through the tubes into a small chamber at the base of the chimney, which served as a smokebox; the area of the grate was 6 sq. ft., and the heating surface of the firebox 20 sq. ft.; owing to the introduction of the boiler tubes, the total heating surface was 138 sq. ft. Two copper pipes, 2·5 in. diam., connected the water space of the firebox with that of the barrel, and two similar pipes placed at the top of the firebox placed it in communication with the steam space of the barrel. The steam from the boiler was admitted to the cylinders by two copper pipes, leading from a regulating cock fixed above the firebox and which received steam from a dome above the barrel through an internal pipe. The boiler pressure was limited to 50 lb. by two safety-valves 2·5 in. diam., one of which was loaded by a spring and lever, while the other was of the lock-up type covered by a dome of tin plate. The feed-water was introduced by a long-stroke pump worked directly from the crosshead, while the exhaust steam was passed into the chimney by two pipes each fitted with a blast nozzle 1·5 in. diam., by which a draught equivalent to 3 in. of water pressure was ultimately obtained.

The framing of the engine is built up of 4 in. by 1 in. bar iron, and the weight is transmitted to the axleboxes by plate springs. The engine weighed, when empty, 3·25 tons, and in working trim 4·25 tons, while the tender, which was a four-wheeled truck carrying a water barrel, weighed, when loaded, 3·2 tons, so that the total weight of the engine and tender in working condition was 7·45 tons. The wheel base was 7 ft. 2 in.

The engine is now standing on some of the original wrought iron rails of the Liverpool and Manchester line, presented by Mr. C. E. Stretton, in 1892 (*see* No. 825).

In 1886 Mr. F. W. Webb, of Crewe, constructed a full-size model of the "Rocket" as it appeared at Rainhill, and a photograph of this is also shown, together with a copy of a drawing prepared by Messrs. R. Stephenson & Co. from original records remaining in their possession, as well as other drawings.

M.341.

194. Model of "Rocket" locomotive and tender (working). (Scale 1 : 8.) Made from drawings prepared in the Museum, 1909.

This model, which is partly in section, represents the famous locomotive "Rocket" as originally built for the Rainhill trials in 1829 (*see* Nos. 193 and

199). It is in general accordance with the known records and relics, but although a great deal of information on its construction has been preserved there are some points of detail upon which uncertainty exists.

The engine ran on four wheels and had two cylinders, 8 in. diam. by 17 in. stroke, placed at the rear end of the boiler and inclined downward at 37 deg. with the horizontal; the piston rods drove the front wheels, which were 56·5 in. diam., thus giving a tractive factor of 19·4. The trailing wheels were 34 in. diam. and the wheel base 7·17 ft. The cylinders were mounted on iron plates, which were bolted to the boiler shell and supported by stays; these plates also carried the guide bars, which were of square section, set diagonally, while the crossheads were of brass, in halves, bolted together and embracing the bars. The steam chests were below the cylinders and the slide valves were driven, through an intermediate shaft and levers, by a pair of eccentrics fixed to a loose sleeve which could be moved endwise along the shaft by a pedal so as to engage with either of two drivers, one set for forward and the other for backward running. The valve rods had gab ends, so that the valves could be disengaged and worked by hand levers when reversing. The crankpins had spherical ends, to allow for irregular motion of the engine relative to the driving axle.

The boiler was a cylindrical shell, 40 in. diam. by 6 ft. long, made in two rings, with a circumferential lap joint and longitudinal butt joints; the flat ends were secured by angle rings and tied together by longitudinal stays. The shell was traversed by 25 copper tubes, 3 in. diam., secured in holes through the end plates. The firebox shown is of the original design, but it is not certain how soon it was altered in shape. It was a separate chamber of copper bolted on to the back end of the barrel. It was rectangular in plan, with a sloping back in which was the fire-door; there were water spaces at the top, back and sides, while there was a firebrick lining in front, below the tubes. Copper pipes connected the water and steam spaces of the firebox with those of the barrel. The total heating surface of the boiler was 138 sq. ft., that of the firebox being 20 sq. ft.; the grate area was 6 sq. ft. The chimney was nearly 15 ft. high, above the rails, and was swelled out at the base to cover the tube ends; it was supported by stays from the cylinder plates.

Steam from the boiler was admitted to the cylinders by two pipes leading from a regulating cock fixed above the firebox and which received steam from a dome through an internal pipe. The boiler pressure was limited to 50 lb. per sq. in. by two safety valves, one of which was loaded by a spring and lever, while the other was a lock-up valve covered by a small dome. A mercurial gauge was fitted beside the chimney and was arranged to indicate the steam pressure from 45 to 60 lb.; a water gauge was fitted behind one of the cylinders and two gauge cocks near the front end of the boiler. The feed water was introduced by a long stroke feed pump worked from one crosshead, while the exhaust steam was passed into the chimney by two pipes, each fitted with a brass nozzle 1·5 in. diam.

The framing of the engine was wholly between the wheels, and was built up of flat bar iron bent down at the rear end to accommodate the firebox and rear axle; to this the cast-iron axlebox guides were secured, and four brackets to support the boiler. The weight was transmitted to the axles by plate springs. The driving wheels were constructed with cast iron bosses, in which the crankpins were fixed, oaken spokes and felloes, and iron tires secured by bolts. The engine weighed 3·25 tons when empty and 4·25 tons in working order.

The tender was a four-wheeled wooden truck carrying the fuel in the body and the water in a large barrel above it. The axles had outside bearings and plate springs, the wheels were 36 in. diam. and the wheel base was 4 ft. It weighed 3·2 tons when loaded, so that the total weight of engine and tender in working order was 7·45 tons. M.3593.

195. The "Sans Pareil" locomotive (1829). Presented by John Hick, Esq., 1864. Plate V., No. 7.

This locomotive was made by Mr. Timothy Hackworth, the engine superintendent of the Stockton and Darlington line, to take part in the Rainhill competition in October, 1829, where, however, it proved unequal to the "Rocket," although in some respects it was a well-built engine. After the trial, however, the engine was purchased by the Liverpool and Manchester Railway Co., and used until 1831, when it was transferred to the Bolton and Leigh Railway. In 1837 the present cylinders, which are larger than the original ones, were substituted, and the wood-spoked wheels were replaced by wheels of cast iron. In 1844 it was removed to Coppull Colliery, near Chorley, where one axle and a pair of wheels were removed, and toothed gearing fitted to the other axle, in order to give motion to pumping and winding machinery. It worked in this way most satisfactorily till 1863, when, on the mine being exhausted, the engine was re-erected as a locomotive and presented to the Museum. The appearance of the engine in 1829 is shown by a copy of the original drawing (scale 1 : 6).

The boiler has a cylindrical shell, 4·33 ft. in diam. and 6·1 ft. long, with one end flat and the other dished; this contains an internal flue, 15 in. in diam., which projects beyond the boiler on the fire grate side, and is enclosed in a water-jacket, thus considerably increasing the grate and heating surfaces. There are two vertical cylinders acting directly downward on crankpins in the driving wheels, which are, however, connected by coupling rods with the trailing wheels, and the engine is without springs. The valves are worked by two loose eccentrics on the driving axle, driven by a clutch in one direction or by another clutch in the other direction when the engine is reversed, there being hand gear to control the valves when reversing in a similar way to that sometimes adopted in early marine engines. The exhaust steam was discharged into the funnel as a powerful blast, and, with the large flue employed, carried over much unconsumed fuel.

The cylinders were 7 in. diam. and 18 in. stroke, acting on four coupled wheels 4·5 ft. diam., giving a tractive power of 16·3 lb. per lb. of mean steam pressure. The boiler had a grate area of 10 sq. ft. and a total heating surface of 90·3 sq. ft. The engine in working trim weighed 4·77 tons; the tender was similar to that of the "Rocket." Dimensioned drawings of the engine are shown.

The "Sans Pareil," as in the case of the "Rocket," is now standing on some of the original Liverpool and Manchester rails, with stone sleepers, which were about 20 in. square and 12 in. deep. M.971.

196. Portions of the "Novelty" locomotive (1829). Presented by the Rainhill Gas and Water Co., 1904. Wheels received 1914.

The "Novelty" was built in 1829 in the short space of seven weeks by Messrs. J. Braithwaite and J. Ericsson to compete at Rainhill for the 500*l.* prize offered by the Liverpool and Manchester Railway Co. During the trials it excited much interest; it attained a speed of 31·9 miles per hour when running light, but owing to breakdowns was unable to fulfil the required tests and was, therefore, withdrawn from the competition. The engine was afterwards run experimentally on the line for some time, and in 1833 it was provided with new cylinders and boiler tubes by Mr. R. Daglish; it was used on the North Union Railway during its construction in 1838, after which its history is unknown. The original cylinders were, however, given to Mr. John Melling, who founded the engineering works at Rainhill, now occupied by the Gas and Water Co., where they remained in partial use until this one was presented to the Museum.

The parts exhibited are: One complete cylinder with its crosshead and guide bars, the pedestal, the two side rods which connected the crosshead with the bellcranks, part of the valve gear, and the wheels. The cylinder is 6 in. diam. by 12 in. stroke, and stands on a small table which forms the bottom cover; the guide bars are round rods tapped into the upper cylinder flange and also serve as cover bolts. The cylinder ports are formed in a

separate brass casting screwed on to the cylinder, and the valve chest is secured to this in a similar manner. The slide valve is driven by two links and a crosshead from levers on a rocking shaft below; this shaft is provided with a double-ended lever having a pin at each end, with which a gab rod, driven by a fixed eccentric on the crank axle, could engage; one pin gives the forward motion and the other the backward. The side rods and the valve rod have been altered at their lower ends to suit their subsequent uses.

The wheels are of the suspension type patented in 1826 by Theodore Jones. The tire is of wrought iron 3·5 in. wide, shrunk on a cast iron rim provided with bosses having conical holes for the heads of wrought iron spokes 1 in. diam. These spokes pass alternately to the one end of the recessed hub, and then to the other, and are there secured by inside nuts so that the spokes cannot be under compression. The nuts are prevented slacking back by an annular plate put over them. The wheels are 4·23 ft. diam.

M.3362 and Inv. 1914–83.

197. Model of the "Novelty" locomotive (working). Scale 1 : 8.) Made from drawings prepared in the Museum, with the assistance of information supplied by A. Braithwaite, Esq., 1905. Plate V., No. 5.

This model represents the "Novelty" as it appeared at the Rainhill trials in 1829. The engine was carried on four equal wheels, 50 in. diam., and had two vertical cylinders, 6 in. diam. by 12 in. stroke, which acted by means of bellcranks and horizontal connecting rods on a crankshaft carrying the single driving wheels. The tractive factor was 8·64.

The boiler consisted of a vertical cylindrical chamber containing the firebox, and a horizontal barrel, 13 in. diam. by 10 ft. in length, containing an internal flue or tube 31 ft. long, tapering from 4 in. in diam. at the firebox end to 3 in. diam. at the chimney; this flue was arranged as a coil of three limbs, and through it the hot gases passed from the top of the firebox, descending to the chimney at the other end of the barrel. The ashpan was closed, and air for the fire was forced in below the grate by a blowing machine worked by one of the bellcranks; there was no blast pipe, the exhaust steam from the cylinders escaping directly into the air. The coke was supplied to the grate down a central tube above the firebox, which was closed by a pair of shutters to prevent its becoming a chimney. The grate was hinged and had an area of about 1·8 sq. ft.; the heating surface of the firebox was about 9·5 sq. ft., and that of the tube about 33 sq. ft. The steam pressure was limited by a spring-loaded valve, and feed water was supplied by a force pump; the locomotive had no tender, but carried a water tank beneath the boiler, and coke in baskets on the platform.

The framing was of wood mounted on springs; the axleboxes and springs were tied together on each side by an iron bar, one end of which was connected with the frame by links. The wheels were of the suspension type (*see* No. 196). The total weight of the engine in working order was 3·85 tons.

M.3416.

198. Model of Brandreth's "Cyclopede." (Scale 1 : 6.) Presented by Admiral Sir T. Brandreth, K.C.B., 1894.

This model shows the machine patented in 1829 by Mr. T. S. Brandreth and entered for competition at the Rainhill trials in the same year. It was a kind of horse velocipede, intended for use on railways, but as the speed attained was only six miles per hour the device was abandoned. The "Cyclopede," with its horse, weighed 3 tons; so that, in proportion to the power exerted, it was very heavy, and would require much more than one horse-power to drive it at any considerable speed. The machine was carried on four flanged wheels, which, by spur gearing, were driven by the endless apron or platform on which the horse walked. This apron was formed of boards 4 in. by 1·5 in., each fitted with end cleats which extended half way

across the adjacent boards, and so distributed the weight. The boards were secured to two endless ropes passing over return pulleys at each end; six intermediate pulleys supported the upper side of the apron, and four the lower or slack side.

The sketch shows the original arrangement of the complete machine; but in the model the apron has a slope of 1 in 13, so that the horse was compelled to walk, as the platform receded under the action of the weight of the animal. This form of horse gear is now used in some districts for driving agricultural machinery (*see* No. 4).

A photograph of a letter from Stephenson to Hackworth regarding this proposal is shown. M.2576.

199. Drawing of the three locomotive engines which competed at Rainhill in 1829. (Scale 1 : 24.) Prepared in the Museum, 1892.

When the Liverpool and Manchester Railway was nearing completion it became necessary for the directors to determine upon the motive power to be employed, and, having received reports from their engineers favourable to the employment of locomotives, they offered, in April 1829, a premium of 500*l.* for the engine which would best fulfil certain conditions, particulars of which are given on an adjacent lithograph.

Messrs. J. U. Rastrick, N. Wood, and J. Kennedy were appointed judges, and the trials were commenced on October 6th, 1829.

Five engines were entered for the competition, viz. :—

The "Rocket," by Robert Stephenson (*see* No. 193).

The "Novelty," by Messrs. J. Braithwaite and J. Ericsson (*see* Nos. 196 and 197).

The "Sans Pareil," by Timothy Hackworth (*see* No. 195).

The "Perseverance," by T. Burstall.

The "Cyclopede," by T. S. Brandreth (*see* No. 198).

The trials were conducted at Rainhill near Liverpool, on a level piece of the line, 1·75 miles in length, of which 220 yards at each end were allowed for starting and stopping. The competing engines were required to make ten double trips, going over the central 1·5 miles at full speed, which was to represent a journey from Manchester to Liverpool. Then a fresh supply of water and fuel could be taken up and the second ten trips performed, which represented the return journey, the average speed throughout to be not less than 10 miles an hour.

The first engine to be tried, on October 8th, was the "Rocket"; it weighed 4·25 tons and had a load of 12·75 tons attached to it. It completed the whole of the double journey at an average speed, over the central portion of the track, of 13·8 miles an hour, its maximum speed for one trip being 24·1 miles an hour.

The next, on October 10th, was the "Novelty," which, on account of its elegant appearance, was the popular favourite; it weighed 3·05 tons, and its load was 7·7 tons, but, after running 3·25 miles, it was stopped by a defective feed pipe. After being repaired it ran an unofficial trip at 19·4 miles an hour. On October 14th it was again brought out and ran about six miles, attaining a maximum speed of 16·1 miles an hour; then some of the boiler joints gave way, and this caused its withdrawal from the competition.

The "Sans Pareil" appeared before the judges on October 13th, when it was found to weigh 4·77 tons, and should therefore have been carried on six wheels. It was thus rendered ineligible to compete for the prize, but was allowed to take its trial. The load attached to it was 14·32 tons, but, after running 27·5 miles at an average speed, over the central portion of the track, of 13·95 miles an hour, and a maximum speed for one trip of 17·5 miles an hour, the feed pump broke down and ended the trial.

The "Perseverance," about which little is known save that it had a vertical boiler with small heating surface, was also tried, but only attained a speed of four or five miles an hour and was withdrawn, while the

"Cyclopede," which was also found unsatisfactory, had a speed of six miles an hour.

The "Rocket," which was the only engine to complete the journeys and fulfil all the conditions, was therefore awarded the prize. These trials convinced the directors of the suitability of the locomotive as a means of haulage. The railway was completed and formally opened for public use on September 15th, 1830. M.2500.

200. Lithograph of "William the Fourth" locomotive (1830). Presented by R. B. Prosser, Esq., 1901.

This was one of two locomotives built in 1830 by Messrs. J. Braithwaite and J. Ericsson, under a contract with the Liverpool and Manchester Railway Co. They were to weigh less than 5 tons and to draw a gross load of 40 tons at a speed of 15 miles an hour on a coal consumption of 5 lb. per ton per mile; they proved failures, however, owing to shortness of steam, and were not accepted.

The engines were of similar construction to the "Novelty" (*see* No. 197). They had four equal wheels 56·5 in. diam., and two vertical cylinders 12 in. diam. by 14 in. stroke. By means of bellcranks and horizontal connecting rods, motion was given to a crankshaft on which the single driving wheels were fixed. The tractive factor was 35·7. The boiler was larger than that of the "Novelty" and differed from it in the manner of producing the draught, the hot gases being exhausted by a fan placed at the end of the flue tube in the vase-shaped structure shown on the top of the steam chamber. The framework was carried on springs and Jones's patent suspension wheels, while fuel and water were carried on a separate tender. M.2758.

201. Drawing of early locomotives built by Messrs. Robert Stephenson & Co., 1825–51. (Scale 1 : 24.) Prepared chiefly from tracings and particulars furnished by C. E. Stretton, Esq., 1898.

The Forth Street works at Newcastle, on the north bank of the Tyne, were established in 1823 by Messrs. George Stephenson, Robert Stephenson, Edward Pease, and Thomas Richardson. The first order was received in 1824 for two engines for the Hetton Colliery Co.; these were of the same size and construction as the first engine represented on the sheet.

No. 3 was built in 1825, and is the famous No. 1 engine of the Stockton and Darlington Railway. It is now preserved at Bank Top, Darlington (*see* No. 190).

No. 9, built in 1826, was a six-coupled goods engine, with two inclined outside cylinders, 9 in. diam. by 24 in. stroke, acting directly upon the crankpins; the driving wheels were 4 ft. diam., giving a tractive power per lb. of mean steam pressure in the cylinders of 40 lb. The boiler had two grates and through furnace flues.

No. 12 was built in 1828, and delivered in January, 1829, to an American canal company. It was a four-wheeled engine, with coupled wheels 4 ft. diam., and two outside inclined cylinders 9 in. diam. by 24 in. stroke.

No. 19 was the famous "Rocket" (*see* No. 193), built in 1829, to the joint order of George and Robert Stephenson.

No. 20 was delivered in 1830 to the Canterbury and Whitstable Railway, now a portion of the South Eastern system. The boiler was subsequently lengthened, and in this condition the engine is still preserved (*see* No. 202). It had four coupled wheels 4 ft. diam., driven by two outside inclined cylinders 10 in. diam. by 18 in. stroke, giving a tractive factor of 37. The boiler, which is subsequent to that of the "Rocket," had twenty-five tubes 3 in. diam. and a

rectangular firebox. An important feature in this engine is that the cylinders are at the forward end, an arrangement that has since been almost universally followed.

No. 29, delivered in October, 1830, to the Stockton and Darlington Railway, was a four-wheeled coupled engine, with the frames passing beneath the axles. There were two inside cylinders, 11 in. diam. by 16 in. stroke, placed beneath the smokebox. The wheels were 5 ft. diam., and the total heating surface was 407 sq. ft.

In 1830–1 Robert Stephenson's partners retired, and he took complete control of the engine works, which he reconstructed. The thirty-seven locomotives already built are not included in the new books, which started with a fresh No. 1, that formed part of an order for three engines for the Stockton and Darlington Railway. The following numbers must therefore be increased by thirty-seven to give their true position in the output of the Forth Street works.

No. 25 was delivered in America in May, 1831. It is a four-wheeled coupled engine, with inside cylinders 9 in. diam. by 20 in. stroke, and wheels 4·5 ft. diam. The firebox is circular in plan. This engine was renamed "John Bull," and is still preserved in working order.

No. 42 was delivered in America in April, 1833; it had a single pair of driving wheels at the back, 4·5 ft. diam. driven by two inside cylinders 9 in. diam. by 14 in. stroke. The front end of the engine was carried on a four-wheeled bogie.

The standard goods engines, built 1835–7, had inside cylinders 15 in. diam., 18 in. stroke, driving four coupled wheels 4·5 ft. diam., and there was a leading pair of smaller wheels; previously these additional wheels had been arranged on a trailing axle. The total heating surface was 571 sq. ft., the tractive factor was 75, and the weight of the engine in working order without tender 14·6 tons.

No. 150, "North Star," was delivered in 1837 to the Great Western Railway, and is famous as the first engine of that line, although not originally designed for it; the link motion shown was added subsequently. It had a pair of inside cylinders 16 in. diam. by 18 in. stroke, and single driving wheels 7 ft. diam., giving a tractive factor of 55. The heating surface was 850 sq. ft. and the grate area 11·76 sq. ft.

The engine "Folkestone," delivered to the South Eastern Railway Co. in 1851, was constructed to a design by Mr. T. R. Crampton, and had a single driving axle behind the firebox with wheels 6 ft. diam., while the front four wheels were 3·5 ft. diam. There was a pair of cylinders 15 in. diam. by 22 in. stroke, arranged under the smokebox and working on a crankshaft, from which, by outside cranks and coupling-rods, the motion was transmitted to the driving wheels. Several of these engines were built, and they attained high speeds, but in general work the arrangement was not satisfactory; they were afterwards all converted to the ordinary form with wheels upon the driving axles. M.2970.

An adjacent lithograph (scale 1 : 96) gives outlines of engines built by the firm between 1825 and 1885. M.3097.

202. Photographs of the "Invicta" locomotive Presented by Sir David L. G. Salomons, Bart., 1907.

This locomotive was built in 1830 by Messrs. R. Stephenson & Co., for the Canterbury and Whitstable Railway. After undergoing various alterations and remaining partially dismantled for many years, it was restored to the condition shown by the photographs and is now preserved at Canterbury.

The engine has cylinders 10 in. diam. by 18 in. stroke, placed in front and inclining downward to drive four coupled wheels 48 in. diam., giving a tractive factor of 37. The valves are placed above the cylinders and driven by sliding loose eccentrics which are reversed by a pedal. When originally built, the boiler was similar to that of the "Rocket," there being a barrel containing 25 tubes 3 in. diam. and a rectangular water jacketed firebox bolted on behind

(*see* No. 203). The firebox and tubes were subsequently removed, the shell lengthened, and a single flue tube fitted. The engine stands on wrought iron fish-bellied rails. M.3525.

203. Original drawings of early locomotives. Lent by Messrs. Robert Stephenson & Co., Ltd., 1901.

These are original working drawings of some of the locomotives built by this firm between 1827–34, for the Liverpool and Manchester and other railways. They include drawings of "Invicta," "Northumbrian," "Planet," "Patentee," and of link motion details, 1842; each has a short description attached. M.3201.

204. Drawing of early locomotives employed on the Liverpool and Manchester Railway, 1829–34. (Scale 1 : 24.) Prepared from tracings and particulars presented by C. E. Stretton, Esq., 1895.

In this drawing eight examples selected from the first thirty-six locomotives used on this line between 1830–34 are shown, and the leading dimensions given, together with a section of the line.

The diagram shows the "Rocket" in its original state, as it was at the Rainhill competition in October, 1829 (*see* No. 194).

The "Northumbrian," which was the finest engine at the opening of the line in September, 1830, very much resembled the "Rocket," as it now is, with its cylinders nearly horizontal.

The "Planet" showed a great change in the arrangement of the locomotive and one that has since become almost universal, the cylinders being placed inside and under the smokebox. A peculiarity of the engine was that the frame passed below the driving axle.

In the "Mercury" the frame was above both axles, and nearly all the other features of the present locomotive are noticeable. This engine was, in December, 1833, converted into a six-wheeler, as shown in red lines.

The "Samson" had four equal wheels, coupled by external rods. On a cotton handkerchief printed in 1831 is represented the opposite side of this engine, showing a large hand-power feed pump, an arrangement that was for some years adopted to prevent delay should the engine-driven pump fail. The above five designs were all carried out by Messrs. R. Stephenson & Co., by January, 1831.

The "Liver," by Edward Bury (*see* No. 206) was a four-wheeled passenger engine, of a type that was afterwards extensively built by him, even after nearly all railways had adopted some form of six-wheeled engine.

The "Patentee," by Messrs. R. Stephenson & Co. in 1834, was a six-wheeled engine, with single drivers in the middle, and no flanges to them. It had a "steam" brake.

The "Swiftsure," by Messrs. Forrester & Co., in 1834, was an outside cylinder engine with single drivers. At the time it was constructed, however, it gave considerable trouble and dissatisfaction owing to the defective balancing of the reciprocating parts and the extreme width between the cylinders. M. 2758.

205. Drawing of the locomotives employed on the Leicester and Swannington Railway, 1832–46. (Scale 1 : 24.) Prepared from tracings and particulars presented by C. E. Stretton, Esq., 1892.

The Leicester and Swannington Railway was commenced in 1830, and opened on July 17th, 1832, Robert Stephenson being the engineer. The main line was 16 miles in length, but included two heavy inclines that could not be worked by locomotives. The Bagworth incline, 950 yards in length, with a gradient of 1 in 29, was worked by a rope, the loaded train from the colliery

at the summit pulling up the empty one; but the Swannington incline, with a gradient of 1 in 17, was, and continues to be, worked by a stationary engine and rope. The remainder of the line had gradients of from 1 in 97 to level. and was worked by the engines illustrated. The gauge was 4 ft. 8·5 in., and the rails of wrought iron of the "fish-bellied" pattern, weighing 35 lb. per yard. Since 1846 this railway has formed part of the Midland system.

Particulars are given of the whole ten engines employed; the "Goliath" and "Hercules," however, are not shown in the drawings, as they were almost identical with the "Samson." The rapid increase in power and heating surface will be seen to be remarkable if the "Comet" of 1832 is compared with the "Atlas" of less than two years later. The "Samson" was the first engine fitted with a steam trumpet or whistle. This trumpet was the suggestion of the manager, Mr. Bagster, to George Stephenson, who had it constructed by a local musical instrument maker.

The "Samson" and "Goliath," owing to their increased length and short wheel base, pitched seriously. To prevent this, Stephenson fitted a pair of trailing wheels behind the firebox, as shown in red, and had the flanges removed from the middle pair of driving wheels. The success was so complete that he decided to discontinue building four-wheeled engines. The arrangement of the "Atlas" was derived from the improved "Samson" class by increasing the size of the added trailing wheels, and then coupling the three axles, but the boiler and cylinders were considerably larger, and the locomotive, which was the most powerful one of its time, weighed 17 tons. The company then purchased the "Liverpool," by Edward Bury, a four-wheeled engine weighing 10 tons; but although it worked well for many years, the succeeding engines were all heavier and closely resembled the "Atlas," although built by other makers. Further particulars of this interesting railway have been collected and published by Mr. Stretton. M.2479.

206. Drawing of early locomotives built by Messrs. Edward Bury & Co., 1830–49. (Scale 1 : 24.) Prepared from tracings and particulars presented by C. E. Stretton, Esq., 1899.

The firm of Messrs. Edward Bury & Co., of the Clarence Foundry, Liverpool, had existed for some years as a general engineering establishment, when, in 1829, they commenced the construction of their first locomotive. During the following twenty years 370 engines were ordered from the firm, but of these forty-one were built for them by other makers and five were never completed, so that the total number finished at the works, which were finally closed in 1850, was 324.

No. 1 engine on the firm's books was the "Dreadnought," completed in March, 1830. It had six coupled wheels, 48 in. diam., connected with an independent shaft upon which two outside inclined cylinders, 10 in. diam. by 24 in. stroke, acted; its tractive factor was therefore 50. The boiler was of the return flue type, with 200 sq. ft. of heating surface, and there was a tender at each end of the engine. This locomotive was from the first unsatisfactory, and was subsequently altered to the four-wheeled type, by the removal of the central axle; but, after having been tried on several railway lines, it was dismantled within ten months of its completion.

No. 2 engine, the "Liverpool," commenced in January, 1831, embodied improvements suggested by the experience gained with No. 1 and by Mr. Kennedy, who had previously been engaged at Stephenson's works. It was a goods engine, with four coupled wheels, 54 in. diam., and a pair of inside cylinders 9 in. diam. by 18 in. stroke, so that its tractive factor was 27. The firebox was of D section, with a domed top; the boiler had ninety-seven tubes and 360 sq. ft. of heating surface, and the framing was of the bar type. There was a single four-wheeled tender, and the whole arrangement embodied the distinctive features of the afterwards well-known Bury type of light engine. At its first trial on the Liverpool and Manchester Railway, in March 1831, it was bought for the Petersburg Railroad of America, on which it worked successfully for several years.

No. 3 engine, the "Liver," built to the order of the Liverpool and Manchester Railway Co., was a four-wheeled passenger engine with a single pair of driving wheels, 60 in. diam., driven by inside cylinders 11 in. diam. by 16 in. stroke, so that its tractive factor was 32. Its weight in working order was 10 tons, and its heating surface 324 sq. ft.; the grate area was a little over 8 sq. ft. The engine ran 22,651 miles in the forty-three weeks that it worked in 1832, and 23,134 miles in the following year.

By the close of the year 1834 sixteen Bury locomotives had been constructed, of which nine had been sent to America; the output subsequently increased, but about 1846 the firm, which had become Messrs. Bury, Curtis & Kennedy, found that the light four-wheeled engine that they had persistently advocated was becoming unpopular, so a six-wheeled type was reluctantly introduced.

No. 190, built for the London and Birmingham Railway, in 1846, had four coupled wheels, 60 in. diam., and a pair of trailing wheels 42 in. diam. The cylinders were 15 in. diam. by 20 in. stroke, and the tractive factor was 75; the heating surface was 795 sq. ft.

No. 192 was also built in 1846 for the London and Birmingham Railway, and was a somewhat similar six-wheeled engine to the preceding, but had single drivers.

No. 220, built in 1846 for the Bristol and Birmingham Railway, had six wheels, 60 in. diam., all coupled and driven by a pair of cylinders 16 in. diam. by 24 in. stroke, giving a tractive factor of 102. The total heating surface was 1,014 sq. ft.

No. 280, built in 1847, followed a design that was accepted by several railway companies. It had four coupled wheels, 60 in. diam., with the firebox placed between their axles, and a pair of leading wheels 48 in. diam.; the cylinders were 16 in. diam. by 22 in. stroke, and the tractive factor was 94. The heating surface was 1,011 sq. ft.

No. 301, built in 1848 for the London and North Western Railway, was a six-wheeled engine with a single pair of drivers, 78 in. diam., and a pair of cylinders 16 in. diam. by 22 in. stroke, giving a tractive factor of 72; in this design Bury abandoned his high-domed firebox, and adopted what he termed his "low-domed" boiler.

No. 355 was the celebrated "Liverpool," built in 1848 for the London and North Western Railway, under Mr. T. R. Crampton's patent. It had eight wheels, but only a single pair of drivers, arranged behind the firebox and driven by outside cylinders. The driving wheels were 96 in. diam., and the cylinders 18 in. diam. by 24 in. stroke, giving a tractive factor of 81; the six other wheels were 48 in. diam. The grate area was 21·5 sq. ft., and the total heating surface 2,290 sq. ft., while the total wheel base was 18·5 ft. and the overall length of the engine 27 ft. The weight of the engine in working order was 35 tons, of which 12 tons were on the driving wheels; the weight of the tender was 21 tons. This engine conveyed express trains from London to Wolverton, and in one case kept time when hauling forty carriages, which was considered to exceed the combined power of three ordinary engines; when tested in 1849 with a light load, the engine attained a speed of 78 miles per hour (*see also* No. 221).

No. 359 was built in 1849 for the Great Northern Railway. It had four coupled wheels 69 in. diam., and a pair of leading wheels 51 in. diam., while the cylinders were 15 in. diam. by 22 in. stroke, giving a tractive factor of 72.

M.3072.

207. Drawing of "Pioneer" locomotive. Presented by C. and C. E. Stretton, Esqs., 1903.

This represents an engine built by Messrs. Rothwell, Hick & Rothwell, at Bolton, in 1832, for the Bangor and Piscataguis Railway, U.S.A.

It was a four-wheeled passenger engine with inside cylinders 9 in. diam. by 18 in. stroke, and driving wheels 54 in. diam., thus having a tractive factor of 27. The valve chests were between the cylinders and the valves driven by loose eccentrics, hand levers being added for reversing. The boiler barrel was

32 in. diam., and contained 47 tubes 1·75 in. diam.; the firebox was of the Bury type, D-shaped with a domed top surmounted by the safety valve; the total heating surface was 182 sq. ft., and the grate area 6 sq. ft. The leading wheels were 36 in. diam. and the wheel base 5 ft.; the frames were of wood flitched with iron plates which also formed the axlebox guards. M.3299.

208. Drawing of early locomotives, built at the Vulcan Foundry, 1833–53. (Scale 1 : 24.) Prepared from particulars supplied by the Vulcan Foundry Co., 1896.

The Vulcan Foundry at Newton-le-Willows, near Warrington, was established in 1832 by Charles Tayleur, of Liverpool, and George Stephenson. At the time Lancashire was a centre of railway enterprise, so that the new works were soon fully engaged in locomotive building as well as on general constructional iron work. Their first locomotive was named "Tayleur," and the second "Stephenson"; both were completed in 1833, and in 1840 the works built their 100th engine. In 1847 the name of the firm was changed from Charles Tayleur and Co. to the Vulcan Foundry Co.

The sheet shows ten of the early locomotives constructed at these works; the examples have been so selected as to indicate the variety in the types then built.

No. 4, built 1833, for the Camden and Woodbury Railroad, U.S.A., was a bogie engine with 9 in. by 14 in. inside cylinders and single drivers 54. in. diam., with the cranked axle behind the firebox, the tractive factor being 21.

No. 8, built 1834, for the Liverpool and Manchester Railway, was a four-wheeled goods engine, with 11 in. by 20 in. inside cylinders and wheels 60 in. diam., the tractive factor being 40·3.

No. 20, built 1835, for the South Carolina Railroad, U.S.A., was a bogie engine, with 10 in. by 16 in. outside cylinders and single drivers 54 in. diam., the tractive factor being 30; the bogie wheels were of two sizes.

No. 25, built 1836, was No. 1 engine of the London and Greenwich Railway; it was a four-wheeled locomotive, with inside cylinders 10 in. by 16 in. and single drivers 60 in. diam., the tractive factor being 21.

No. 35, built 1836, for Mr. Hargreaves, of Bolton, was a six-wheeled engine with four coupled drivers 68 in. diam. and 13 in. by 18 in. inside cylinders, the tractive factor being 45. It is shown on stone sleepers and a parallel rail of the period.

No. 52, built 1837, for the Great Western Railway (7 ft. gauge), was a six-wheeled engine with single drivers 96 in. diam., and 14 in. by 16 in. inside cylinders, the tractive factor being 33.

No. 61, built 1838, was a light engine used by a contractor on the London and Birmingham line. It had 12 in. by 16 in. inside cylinders and 54 in. single drivers, the tractive factor being 43.

No. 231, built 1845, for the line between Bristol and Birmingham, was a six-wheeled engine with single drivers behind, 72 in. diam., and 15 in. by 24 in. outside cylinders, arranged between four wheels of equal size; the tractive factor was 75.

No. 316, built 1848, for the Shrewsbury and Chester Railway, was a four-wheeled inside cylinder engine with a wheel base of 11·5 ft. The wheels, 63 in. diam., were coupled to an intermediate axle, which was driven by 16 in. by 24 in. inside cylinders, giving a tractive factor of 97·5.

No. 346, built 1853, for the Shrewsbury and Hereford Railway, was a six-wheeled engine, with single drivers 66 in. diam., driven by 15 in. by 20 in. inside cylinders, but with the valve chests and motions outside the frames; the tractive factor was 68. M.2918.

A lithograph on the wall shows the firm's practice in 1838, while on the Leicester and Swannington sheet (*see* No. 205) is shown another engine by the Vulcan Co.

209. Six sheets of diagrams of locomotives. (Scale 1 : 96.) Presented by Theodore West, Esq., 1886.

The original diagrams of which there are lithographs, were prepared to illustrate a paper read by Mr. West before the Cleveland Institution of Engineers in 1886, on the development of the locomotive in this country and America. The outlines are to scale, and the leading dimensions and particulars of the engines, are given on the sheets. M.2769

210. Photograph of "Hibernia" locomotive. Received 1865.

This was one of the three engines built in 1834 by Messrs. Sharp, Roberts & Co., of Manchester, for the Dublin and Kingstown Railway. They were of a novel type proposed by Richard Roberts, the cylinders being placed vertically over the centre line of the leading wheels, and working the driving wheels by connecting rods and equal-armed bellcranks. The cylinders were 11 in. diam. by 16 in. stroke, and the driving wheels 60 in., giving a tractive factor of 45; the leading wheels were 36 in. diam. There were no eccentrics to actuate the valves, short arms on the bellcranks being used instead to move rocking shafts near the foot-plate. The valves were tubular without lap or lead, and the pistons were without rings, but had white metal bands exactly fitting the cylinders.

The engines proved unsteady in running, so that, with the exception of the "Experiment," for the Liverpool and Manchester Railway, no others were built. M.2767.

211. Diagram models of balanced locomotive with expansion valves (working). (Scale 1 : 3.) Contributed by R. Bodmer, Esq., 1857.

These two models show the method of balancing the reciprocating parts of a locomotive patented by Mr. J. G. Bodmer in 1834, and tried with some success in 1844–6. Each cylinder has two pistons, one with a tubular rod within which the other rod slides; the pistons, being connected with cranks set at 180 deg. with one another, continually move in opposite directions, thus almost completely balancing their inertia stresses. The cylinders have a port at each end and another at mid length. The end ports are led to one of the steam ports of an ordinary three-ported valve face, and the middle one to the other port, so that the steam is distributed by an ordinary slide valve.

The models show the application of a right and left hand screwed valve spindle, as a means of changing the point of steam cut-off by altering the amount of valve lap. Mr. J. G. Bodmer in 1841 patented this arrangement as applied to a piston cut-off valve working in a separate chest at the back of the ordinary valve. Later in the same year, Mr. Horatio Allen patented, in America, the usual form with flat valves, and with the cut-off valve working upon the back of the main valve, while, in 1842, the same arrangement was patented in France by Mr. J. J. Meyer, by whose name it is generally known.

One model shows a cylinder and its gearing for an outside cylinder locomotive. The valves are of the piston form, and the cut-off valve works within the main valve and has a screwed spindle to give a variable lap; the main valve spindle is hollow and the other slides within it. The other model represents two cylinders, valves, etc., for an inside cylinder engine, the valves being of the Meyer type (*see* No. 264), and placed between the cylinders. The cut-off valve spindles are geared together and are rotated from the foot-plate. The reversing gear, which was of the ordinary kind, is not shown on the models. Inv. 1857–1 & 2.

212. Model of passenger locomotive, 1837 (working). (Scale 1 : 12.) Received 1896.

This model was made by Mr. J. Dawson, District Superintendent at Southampton, of the London and Southampton (now the London and South Western) Railway. It represents an engine of the standard passenger type of

the period. It had six wheels, a single driving axle, inside cylinders and outside frames.

The cylinders were 12 in. diam. by 18 in. stroke, and the driving wheels were 60 in. diam., so that the tractive factor was 43. The leading and trailing wheels were 42 in. diam., and the wheel base was 11 ft. The smoke-box completely enclosed and supported the cylinders, but the valves were placed above them and not between, as generally arranged somewhat later. The crosshead guides were of the four-bar type, and above them were arranged rocking shafts for driving the slide valves.

As this model was made before the introduction of the now almost universal link motion, its valve gear is of particular interest. The valve of each cylinder was provided with two eccentrics, one for forward running and the other for backward; the ends of the eccentric rods finished in notches or gabs and were supported by links from a horizontal reversing shaft. Each pair of gabs embraced a pin connected with one of the slide valve rods. By a lever on the right-hand side of the platform the reversing shaft could be turned so as to throw one set of gabs off the valve pins and the other set on, or leave them in the intermediate position when the valve rods were free for independent movement by the hand levers, which were on the left side of the platform, one lever being provided for each cylinder. This gear entailed the manipulation of three levers in reversing and gave no means of altering the cut-off, but it contained the four eccentrics of the present locomotive link motion.

The boiler had a barrel 42 in. diam. and 8 ft. long, with a firebox of circular section having a domed crown; the inner firebox was flattened to form the tube plate. A spring-loaded safety valve was mounted on a dome over the firebox and another on the barrel. Two long stroke feed pumps were provided, driven directly from the crossheads.

The frames shown are of solid bars, but it is probable that they were intended to represent the early timber frames which were flitched with iron plates on both sides. The boiler was carried on wrought iron brackets resting on the frames. There was no shelter for the driver, the only protection on these early locomotives being a handrail as shown. M.2939.

213. Drawing of early locomotives of the Great Western Railway, 1837-55. (Scale 1 : 24.) Prepared chiefly from particulars and tracings furnished by C. E. Stretton, Esq., 1898.

The prospectus of the Great Western Railway Co. was issued in 1833, the Act authorising construction was passed in 1835, and the broad gauge of 7 ft., proposed by Brunel in 1835, was sanctioned by Parliament in 1837. The first section of the line, from Paddington to Maidenhead, a distance of 22·5 miles, was opened in 1838, and the line to Bristol in 1841; the extensions to Cornwall, South Wales, and Cheshire were carried out subsequently. The rails used were of the bridge section, weighing 44 lb. per yard, and were supported on longitudinal sleepers resting on short piles and tied together by transoms (*see* No. 848A. The piles were soon abandoned, but the longitudinal system was retained, the extra width of the broad gauge probably rendering it more economical than the use of transverse sleepers. In 1845 the railway had 274 miles of line laid with the broad gauge exclusively; in 1854 the mixed gauge, obtained by the use of three rails, which had been introduced in 1847, was extensively adopted; but by 1867 the broad gauge track had increased to 1,456 miles. In 1869 was commenced the conversion of some of the mixed gauge track into narrow gauge, and at the same time the manufacture of unconvertible broad gauge stock was restricted; in 1892 the broad gauge rolling stock was entirely withdrawn, and the system has since been worked exclusively on the standard gauge of 4 ft. 8·5 in. An adjacent photograph shows the last broad gauge mail train leaving Paddington station, May 20th, 1892.

The first engine of the Great Western Railway was the "North Star," built in 1837 by Messrs. R. Stephenson & Co., although not designed for

this line. It remained in use till 1870, and ran more than 400,000 miles. It had a pair of inside cylinders 16 in. diam. by 18 in. stroke. and single driving wheels 7 ft. diam., giving a tractive factor of 55. The heating surface was 850 sq. ft., and the grate area 11·76 sq. ft. The link motion shown was added some years after the engine was built. This engine was the first of twelve forming the "Star" class, all built for this line by Messrs. R. Stephenson & Co. in 1837–41.

"Vulcan," the second engine of the line, was built in 1837 by the Vulcan Foundry Co., being No. 52 in their books. It was a six-wheeled engine with single driving wheels 96 in. diam., and inside cylinders 14 in. diam. by 16 in. stroke; the tractive factor was 32·6.

"Lion," the seventh engine of the railway, was built by Messrs. Sharp, Roberts & Co. in 1838. It was a six-wheeled engine with inside cylinders 14 in. diam. by 18 in. stroke, and a pair of single 6 ft. driving wheels. The tractive factor was 49.

"Ajax," the fifteenth engine on the line, was built in 1838 by Messrs. Mather, Dixon & Co., of Liverpool. It was a six-wheeled engine with inside cylinders and outside frames and axle bearings; the cylinders were 14 in. diam. by 18 in. stroke, and drove a single pair of driving wheels 8 ft. in diameter, giving a tractive factor of 36·7. These wheels were without spokes, two discs of boiler plate held together by screwed stays being substituted in each; the discs, which were 0·56 in. thick, were 7 in. apart at the boss and 3·5 in. at the rim.

"Fire-fly" was built in 1840 by Messrs. Jones, Turner, and Evans, to designs by Sir D. Gooch. It had a pair of inside cylinders 15 in. diam. by 18 in. stroke and single drivers 7 ft. diameter; the tractive factor was 48, and the engine in working order weighed 24·2 tons. Altogether sixty engines to this design were constructed by various makers.

"Iron Duke" was built at the Swindon Works in 1847 to designs by Sir D. Gooch; the cylinders, 18 in. diam. by 24 in. stroke, worked single drivers 96 in. diam., thus giving a tractive factor of 81. The grate surface was 21 sq. ft., and the total heating surface 1,952 sq. ft. The "Iron Duke" is shown with its tender, as both remained for many years the standards for the Great Western line, until the abolition of the 7 ft. gauge was definitely decided upon. The engine had four small wheels in front, with the axle-boxes on each side connected by a single plate spring, which acted also as an equalising lever, an arrangement that was extensively adopted for many years, but was ultimately replaced by the bogie.

"Lalla Rookh" was built in 1855 by Messrs. R. Stephenson & Co., to designs by Sir D. Gooch; it had 17 in. cylinders by 24 in. stroke, and coupled drivers 7 ft. in diameter, giving a tractive factor of 82·5. This adaptation of the "Iron Duke" design to an engine with coupled drivers was followed in ten engines, but was not afterwards repeated. M.3017.

214. Photographs of early American locomotives. Presented by C. E. and C. Stretton, Esqs., 1900.

These were taken from the relics and models of America's first locomotives, dating between 1831 and 1844, as exhibited at Chicago in 1893. Each has a short description beneath it. M.3103.

215. Model of early Austrian locomotive (working). (Scale 1 : 6.) Made by Philipp Wolf. Received 1902.

This model, which was made in 1843, represents a type of locomotive, introduced in 1837 by William Norris of Philadelphia, for working on lines having steep inclines and sharp curves; such engines were largely used on the Austrian railways at their commencement in 1838, and many of the class were subsequently built at Vienna. Similar locomotives were sent by Norris to England in 1840, and some of them were used for working the Lickey incline on the Birmingham and Gloucester Railway.

The engine represented had inclined outside cylinders, and a single driving axle in front of the firebox, while the forward end of the engine was carried by a four-wheeled swivelling bogie, so that great flexibility was secured. The cylinders were 10·5 in. diam. by 21 in. stroke and the driving wheels 46.5 in. diam., so that the tractive factor was 50; the bogie wheels were 30 in. diam., with their centres 2·875 ft. apart, while the total wheel base of the engine was 9·875 ft. on a gauge of 5 ft. Each cylinder was provided with two square guide bars, and the crossheads working on them had adjustable slide blocks.

The valve chests were arranged above the cylinders, and the valve rods were driven, through a rocking shaft, by four eccentrics on the driving axle. There was a forward and a backward eccentric to each cylinder, and each eccentric rod ended in a notch or gab provided with a spreading jaw or fork; the gab ends of each pair of rods faced each other and were suspended by links from a reversing shaft actuated by a lever on the foot-plate, so that either the forward or the backward eccentrics could be used for actuating the valves. As there was no intermediate position, this valve gear did not permit of the grade of expansion being altered, so that the speed was regulated entirely by throttling.

The boiler was tubulous, with a barrel 8·25 ft. long by 38 in. diam. and it had a dome firebox of the Bury type, while the grate was D-shaped in plan; the heating surface was probably 400 sq. ft. and the grate area 6 sq. ft. The dome was surmounted by a spring-loaded lever safety valve, while over the middle of the boiler barrel was a locked-up safety valve directly loaded by plate springs. The regulating valve was of the sliding type, manipulated by a vertical lever above the fire-door; the model shows also a glass water-gauge and a steam whistle. The feed water was introduced by two long-stroke feed pumps, directly driven from the crossheads, and special arrangements were made to render the pump and check valves readily accessible; the suction pipe of each pump was fitted with a cock controlled from the footplate.

The frame was of the bar construction, and the boiler was supported from it by brackets; the framing rested on the bogie carriage at each side, while a central swivel pin connected it with the bogie. The horns were forged with the framing, which was strengthened by inclined struts passing under the horns and riveted to the framing at each end; the driving axle and those of the bogie were provided with separately adjustable plate springs. The footplate was carried by an extension of the framing and was fitted with an hand rail, but no protection against the weather was provided; the length of the engine was 20 ft., and its weight in working condition about 10 tons.

The tender was built on double frames with the springs and axleboxes between them; the water tank was of a horse-shoe shape, and the central space was the fuel receptacle. The tender was carried on four wheels, 30 in. diam. and had a wheel base of 4·875 ft.; it was fitted with brake blocks between one pair of wheels and the brakes were applied by a screw actuating a vertical wedge. The engine and tender were closely connected by a pin coupling, and were provided with two padded buffers at the ends; the overall length of engine and tender was 32 ft. and the total weight about 14 tons. M.3212.

216. Drawings of experimental locomotives on the Great Western Railway. (Scale 1 : 24.) Presented by C. E. Stretton, Esq., 1891.

These blue prints represent the engines "Hurricane" and "Thunderer," designed by Mr. T. E. Harrison, and constructed by Messrs. R. and W. Hawthorn, of Newcastle, in 1838. In both engines the plan, patented by Mr. Harrison in 1836, of separating the boiler from the engines was followed. The object of the arrangement was to enable a fresh boiler carriage to be attached to the engine carriage, while the former was under repair, and *vice versâ*.

The "Hurricane" had two cylinders 16 in. diam., 20 in. stroke, working direct on to single driving wheels 10 ft. diam. The "Thunderer" had two cylinders 16 in. diam., and 20 in. stroke, working on to a crankshaft which, by spur gearing in the ratio 3 : 1, was connected with four coupled driving wheels 6 ft. diam.; the gearing made the equivalent diameter 18 ft. Both engines were failures, probably largely owing to the weight on the driving wheels being so small. M.2382.

217. Photographs of London and North Western locomotives. Lent by A. M. H. Solomon, Esq., 1899.

These show typical engines used on this line between 1839–99. Each photograph has a short description beneath it. M.3068.

218. Model of "Bury" passenger locomotive (working). (Scale 1 : 12.) Received 1905. Plate V., No. 8.

This model, which was made in 1846, represents a type of locomotive introduced by Edward Bury & Co. in 1832 (*see* No. 206), but the engine shown was built about 1840, probably for the Midland Counties Railway. The engines of Bury's design were of very simple form, having only four wheels and inside cylinders directly attached to inside bar framing, so that no driving stresses were imposed on the boiler. The crankshaft had two bearings only instead of the five or six usual at the period. The feature of the boiler was the D-shaped firebox with its high domed crown. These four-wheeled engines were found to oscillate considerably at high speeds, but this defect was remedied by introducing a pair of trailing wheels as shown in the model. Locomotives of this type were employed on many lines and exclusively used on the London and Birmingham Railway from 1837 to 1846.

The engine represented had horizontal cylinders 12 in. diam. by 18 in. stroke and single driving wheels 66 in. diam. placed in front of the firebox; the tractive factor was 39·3. The leading wheels were 48 in. diam. and the trailing wheels 36 in. diam. The cylinders were bolted to a pair of cross-bars secured to the frames at their ends, and were each provided with four guide bars. The valve chests were placed above the cylinders, in the smoke-box, and the valve rods were driven through rocking shafts by four fixed eccentrics on the driving axle. There was a forward and backward eccentric to each cylinder and the eccentric rods had notches or gabs at their ends, provided with long spreading jaws opening downward, which engaged with pins on the valve levers. One rod of each pair was suspended from a lever on a reversing shaft which was cranked backward in the middle, while the other two were hung from a lever pivoted at one end and having a slot engaging with the crank. The reversing shaft was actuated by a lever on the footplate, so that one pair of forks was lowered into gear while the other pair was lifted out; this reversing gear did not permit of variable expansion. The addition of forks to the gabs enabled the eccentric rods to be put in gear at any position of the valves, and thus dispensed with the levers necessary in the earlier gears for working the valves by hand.

The boiler barrel was 37·5 in. diam. inside and 8·21 ft. long, the D-shaped firebox being 47·5 in. wide and 39·5 in. long; the internal firebox was of iron. There were eighty-six tubes, 1·875 in. external diam., having a heating surface of 362 sq. ft.; the firebox heating surface was 38 sq. ft., and the grate area 7·6 sq. ft. A small dome on the top of the firebox accommodated the steam pipe and was surmounted by a spring-loaded lever safety valve, while on the barrel was a lock-up safety valve directly loaded by a helical spring. The regulator was of the rotary type manipulated by a lever over the fire-door; a fitting was attached on one side of the firebox carrying a water gauge, cocks, and a whistle. The feed water was introduced by two long-stroke feed pumps driven directly from the crossheads.

The frame was formed of single flat bars having the axle box guides forged or bolted on, and was trussed with round bars; the boiler was supported from it by brackets. The draw-bar was attached to a stirrup secured to the frames and embracing the firebox; the axles were provided with separate plate springs placed above them. The wheels were built up with cast iron naves and wrought iron spokes, rims, and tires. The spokes had T heads riveted to the rims, while their inner ends were coned and cottered into sockets in the naves. The footplate was carried on the rear end of the frame and was fitted with a hand rail. The length of the engine was 17·75 ft. and its total wheel base 10·42 ft., but only 5·5 ft. without the trailing axle; its weight in working order was about 11 tons, of which 6 tons were carried by the driving wheels.

A tender was made from drawings prepared in the Museum, and was added to the model in 1906 to complete the exhibit; it represents the form in general use from about 1833–1840. This tender, which was carried on four wheels 36 in. diam., had a wheel base of 4·58 ft. The framework was built up of wooden beams, the side frames being double with the wheels between them and covered on the outside with ornamental iron plates. The water tank was of horse-shoe shape and rested on the top of the frames, being held by large angle irons at the corners; the coal space between the frames was lined with sheet iron. The bearings were outside the wheels with the plate springs above them. Wooden brake blocks were fitted between the wheels on one side, and these were applied by a screw actuating a vertical wedge. The buffers were padded and mounted on sliding stems which engaged with the ends of a transverse spring. The engine and tender were closely connected by a link and pin coupling having swivel joints. The tank held 640 gal. of water and about 10 cwt. of coal were carried.

The weight of the engine and tender in working order was about 17·5 tons and the overall length 30·1 ft. M.3399.

219. Model of passenger locomotive, 1845. (Scale 1 : 5.) Received 1908.

This sectional model represents the type of locomotive that was in general use about 1840–45. It had six wheels, a single driving axle, inside cylinders and outside frames.

The cylinders were 12·5 in. diam. by 21 in. stroke, and the driving wheels were 62·5 in. diam., so that the tractive factor was 52·5. The leading wheels were 36·5 in. diam., and the trailing ones 33 in. diam.; the wheel base was 11·8 ft. The smokebox completely enclosed and supported the cylinders; the valve chests were above the cylinders, and the valves were driven through a rocking shaft by four eccentrics and the ordinary link motion, but it is probable that the engine represented was originally fitted with a gab gear. The crossheads were guided by four bars whose outer ends were supported on a transverse plate frame.

The boiler barrel was 37·75 in. diam. and 8·33 ft. long. The firebox was 44·5 in. long and 47·5 in. wide, and was fitted with a transverse water pocket in the lower part, a common feature at that period. There were 98 tubes, of 2 in. external diam., having a heating surface of 450 sq. ft.; the firebox heating surface was 80 sq. ft., and the grate area 7 sq. ft. A dome over the firebox carried a spring-loaded lever safety valve, while another dome on the barrel accommodated the regulator valve which was of the rotary butterfly type. The feed water was introduced by a short-stroke feed pump fixed to the back of the smokebox, below the barrel, and driven by an eccentric on the crankshaft.

The frames were formed of wooden beams, flitched on both sides with iron plates, which also formed the axlebox guides; they were trussed with round iron rods and tied together by the buffer beams and the central transverse plate. The plate springs for the driving axle were placed above the frames, and those for the other axles between the horn plates below them.

Two inside iron frames, having additional bearings for the crankshaft, extended between the smokebox and the firebox, to which they were secured. The boiler was supported by four brackets bolted to the outside frames, and the barrel also rested upon the transverse plate. The rear draw bar and the two side buffers were connected by a horizontal plate spring, and the footplate was provided with hand rails only. The overall length of the engine was 19 ft.

M.3544.

220. Model of long boiler locomotive. (Scale 1 : 8.) Lent by G. Stephenson, Esq. 1914.

This model, probably made about 1845, represents the type of locomotive patented by Robert Stephenson in 1841. It was known as the "long-boiler" engine, and many of this pattern were built subsequently by Messrs. R. Stephenson & Co. The chief features of the design were the placing of the three axles under the boiler barrel, an arrangement which allowed the use of a larger boiler on an engine having a normal wheelbase, while the slide valves were placed vertically beside the cylinders. The driving wheels were without flanges, to obviate lateral stresses on the crank axle; this feature had been patented by Robert Stephenson in 1833.

The engine represented had outside horizontal cylinders 14 in. diam., by 22 in. stroke, and driving wheels 86 in. diam., so that the tractive power was 65·3. The leading and trailing wheels were 42 in. diam., and the wheel base was 10·5 ft. The cylinders were bolted to the frames and were stayed together below. The valves were directly driven by Howe link motion, the links being of box form. The crossheads were guided by two bars, and the connecting rods were forked.

The boiler barrel was 38 in. diam., and 12·33 ft. long; it contained about 130 tubes, 1·75 in. diam., having a heating surface of 700 sq. ft. The firebox was of the haystack form, 44 in. wide and 46 in. long, its grate area being 9 sq. ft., and the heating surface 51 sq. ft.; the regulator was placed in the upper part which was surmounted by a pair of spring-loaded lever safety valves. A water-gauge, cocks, and whistle were fitted, as well as a steam blower and cylinder cocks. The feed water was introduced by two short-troke feed pumps driven by the backward motion eccentrics.

The main frames were single vertical plates placed inside the wheels, while the horns were formed by double plates rivetted to them; the boiler was bolted to them at the ends and also to brackets at the middle. The drawbar was attached to cross-plates fixed to extensions of the firebox side plates which were made very thick. The axles had separate plate springs placed above the frames. The engine weighed about 21 tons, of which 10 tons rested on the driving wheels; the overall length was 23·8 ft.

221. Model of Crampton's locomotive (working). (Scale 3 : 20.) Lent by T. R. Crampton, Esq., 1876. Plate VI., No. 1.

This represents an express passenger engine of the type designed and patented by Mr. Crampton in 1842–47, and built by MM. Derosne et Cail, Paris, for the Northern Railway of France, in 1849. The general arrangement shown was adopted in order to keep the centre of gravity low, and at the same time to use large single driving wheels which were carried on an axle behind the firebox. Locomotives of this design worked the French express services from 1849 until about 1876, and Crampton engines of the Folkestone class (*see* No. 201) ran for a time on the South Eastern and the Great Northern Railways. Four-coupled engines with the same arrangement of mechanism were also employed on the London, Chatham, and Dover line.

The engine was carried on six wheels and had outside cylinders 15·75 in. diam. by 22 in. stroke; the driving wheels were 82·6 in. diam., and the tractive factor 66. The piston rods were extended through the front cylinder covers and formed plungers for long stroke feed pumps. The valve chests

were on the tops of the cylinders, inclined outward, and the valves were driven by eccentrics, mounted on a return crank, through the usual shifting link motion, so that the whole of the mechanism was exposed to view and easily accessible. The frames were double and tied together by transverse stays, and the cylinders were bolted between the plates of each frame. The two leading axles had outside bearings and the driving axle inside bearings only, the load being suspended by laminated springs placed above them.

The boiler barrel was 4 ft. diam., and 11·92 ft. long between the tube plates, its centre being only 4·72 ft. above the rails. It contained 173 tubes of 2 in. external diam. and four tubes of 1·75 in. diam., these having a heating surface of 1,070 sq. ft.; the firebox had a heating surface of 79 sq. ft. and a grate area of 15·4 sq. ft. The regulator was placed in a chamber on the barrel and external steam pipes led to the cylinders. Two spring-balance safety valves were provided. The smokebox was formed as an extension of the boiler barrel, and the two exhaust pipes were led to a blast nozzle having an orifice whose area was adjustable by means of two hinged flaps.

The rigid wheel base of the engine was 15·94 ft.; the front wheels were 51 in. diam. and the middle ones 48 in. diam. The weight of the engine in working order was 27 tons, the leading and driving wheels carrying 11·5 tons each and the middle ones only 4 tons, this distribution being adopted to ensure steady running. The tender was carried on four wheels 42·2 in. diam. with a wheel base of 8·2 ft.; it had hand brakes on the wheels and a horse-shoe shaped water tank. The overall length of engine and tender was 45 ft.

M.1787.

222. Model of passenger locomotive and tender (working). (Scale 1 : 9.) Received 1906.

This represents the type of inside cylinder passenger engine which was in general use for many years subsequent to its introduction by Mr. John Gray in 1846; its extensive use was, however, largely due to the success of the engine "Jenny Lind," built by Messrs. E. B. Wilson & Co., of Leeds, in 1847. These engines had six wheels, double frames, and a single driving axle having inside bearings only, while the leading and trailing axles had outside bearings.

The model shows an engine of this type built about 1860. It had double slab frames running from end to end and braced by the cylinders and transverse frames. The cylinders were placed horizontally under the smokebox with the valve chests between them. The valves were driven by Howe's link motion. The intermediate valve rod was suspended by a link, and reversing was effected by a lever and quadrant, through a weighted countershaft below. Each crosshead had four guide bars whose rear ends were supported by a transverse plate which also supported the boiler barrel and the reversing shaft. The boiler was provided with a steam dome on the barrel surmounted by a spring-balance safety valve, and the usual fittings on the back plate of the firebox. The feed water was supplied by two long stroke feed pumps bolted to the frames and driven directly by the crossheads. A simple weather plate was provided for the protection of the driver and fireman.

The tender was carried on six wheels and was fitted with brakes which were applied by a hand wheel and screw. M.3448.

223. Photographs of Tredegar locomotive. Prepared in the Museum, 1898.

These show the locomotive "Bedwellty," built by Mr. Thos. Ellis in 1853 for the Tredegar Iron Co., and used in hauling coal, &c. on the Sirhowy tramway between Tredegar and Newport.

This engine, and eight others built at Tredegar between 1832 and 1848, were six-coupled engines with inclined cylinders at the rear end driving on to the front axle. They were similar in general design to the first engine

made for the company, by Messrs. R. Stephenson & Co., in 1829, of which the original drawing is shown in No. 203. In 1882 it was discarded, and some time later the upper photograph was taken; the lower two photographs are much more recent and show the engine dismantled. After 1860 the tramway was converted into a railway. M. 3021.

224. Great Northern Railway locomotive. (Scale about 1 : 16.) Lent by Lieut.-Col. J. D. K. Restler, 1918.

This model, which is one of a collection formed by the late Sir James Wm. Restler, probably represents an engine built in 1853, to the designs of Mr. A. Sturrock, and subsequently rebuilt about 1855 or 1860. It had six wheels, a single driving axle, inside cylinders and double frames.

The cylinders were 16 in. diam. by 22 in. stroke, and the driving wheels were 74 in. diam., so that the tractive factor was 76·1. The steam chest was placed between the cylinders and the valves were driven by Howe's link motion controlled from the foot-plate by a lever and quadrant. The screw gear shown was probably a later addition. The cross-heads were guided by four bars the outer ends of which were supported on a transverse plate frame.

The boiler barrel was 4 ft. diam, and 10 ft. long; it contained 171 tubes of 2 in. external diam., having a heating surface of 874 sq. ft. The fire-box heating surface was 114 sq. ft., and the grate area 13·64 sq. ft. A dome on the barrel contained the regulator valve and was surmounted by a pair of spring loaded lever safety valves. The feed water was introduced by a pair of long stroke feed pumps driven directly from the crossheads. The double frames were of iron with axle bearings in the outer plates only; the springs were placed above the frames. The overall length of the engine was 24·4 ft. and its weight in working order was 27·8 tons.

The tender ran on six wheels 4 ft. diam. with a wheel base of 12 ft.; it was fitted with brakes which were applied by a hand wheel and screw. The water tank had a capacity of 1,500 gal. Inv. 1918–196.

225. Model of Indian locomotive and tender. (Scale 1 : 4.) Contributed by Lieut.-Col. J. P. Kennedy, 1863.

This represents an engine, built in 1856 by Messrs. E. B. Wilson & Co., at the Railway Foundry, Leeds, for the Bombay, Baroda, and Central India Railway, then in process of construction. The design is almost identical with Mr. Alexander Allan's "Crewe" class of goods engines, built at the Crewe Works between 1843 and 1857.

It had outside inclined cylinders 14 in. diam. by 24 in. stroke, and four coupled driving wheels 60 in. diam., giving a tractive factor of 78·4. The framing was double, the inside frames carrying the cylinders and the axle-boxes for the coupled wheels, while the outer frames carried the axleboxes for the leading wheels, which were 40 in. diam. The engine was fitted with Howe's link motion with suspended valve rods, and two feed pumps were driven from the two inner eccentrics. Two spring-balance lever safety valves were fitted to the boiler, one on a dome over the firebox, and the other on the barrel. The engine weighed about 22·4 tons; the gauge was 5·5 ft.

The tender ran on six wheels, brake-blocks, applied by a screw and hand wheel, being fitted to the three wheels along one side only. M.909.

226. Drawing of steam carriage. (Scale 1 : 8.) Presented by G. Stephenson, Esq, 1914.

This drawing shows a combined locomotive and carriage built by Messrs. R. Stephenson & Co., in 1859, for Said Pasha, Viceroy of Egypt. The locomotive was an inside cylinder, four-wheeled. single driving engine with the framing extended rearward and carried on a four-wheeled bogie. The

cylinders were 8 in. diam. by 14 in. stroke and the driving wheels 60 in. diam. The leading and bogie wheels were 42 in. diam., the fixed wheelbase was 8.58 ft., and the total wheelbase 22.25 ft. The boiler had a total heating surface of 409 sq. ft., and a grate area of 6.7 sq. ft. A water tank holding 400 gal. was fitted below the boiler, and the fuel capacity was 4·5 cwt. The carriage had a coach-shaped body and was mounted on the frame extension; its roof was carried forward to cover the footplate and firebox. The vehicle was lavishly decorated as were some other engines on the Cairo and Alexandria Railway at this time. The rails were laid on cast-iron pot sleepers. Inv. 1914—868.

227. Model of an Egyptian locomotive (working). (Scale 1 : 8.) Lent by T. Jeffrey, Esq., 1870.

This represents a tank engine built in 1862 at Alexandria by Jeffrey Bey, for working the train service between Alexandria and Suez.

It is a four-wheeled engine with a single pair of drivers 5 ft. diam.; the cylinders are of the outside type, 13 in. diam. and 20 in. stroke, giving a tractive factor of 56. The valve gear is of the usual shifting link form; the valve boxes are inside, and two long stroke feed pumps are arranged beneath the cylinders, the plungers being directly connected with the crossheads. The tank is arranged beneath the boiler, and the weigh shaft for the link motion is carried through a horizontal tube in the tank. The smokebox is produced downward and formed into a second tank, which is an extension of the main one. Two coal bunkers are arranged, one on each side of the firebox, whereby the overall length of the locomotive is reduced. The blast pipe terminates in a series of nozzles superposed. The gauge fittings are all fixed to a water column attached to the boiler. The various accessories carried by a locomotive are also shown, including a traversing screw jack, the stoking and firing irons, fire-bars, lanterns, etc. The engine is provided with a hand-brake, which acts on the driving wheels, and a light cab is fitted over the footplate to afford shelter from the intense heat of the sun. M.1828.

228. Model of a six-coupled goods engine (working). Received 1892.

This represents an inside cylinder engine with six coupled wheels 4 ft. diam. The cylinders incline slightly downward, so that while high enough to clear the leading wheels, they act directly on the central driving axle, which has two cranks at right angles and also the four eccentrics of Stephenson's link motion. The cylinder slide valves are above the cylinders, and receive their motion through a weigh shaft. The feed is supplied by a vertical flywheel donkey pump at the side of the firebox, this model having been made before the general use of the injector. The method in which three axles are coupled so that the adhesion of all six wheels is utilised for traction, is also clearly shown.

The tender is fitted with six wheels and provided with a powerful hand-brake. M.2447.

229. Model of American locomotive (working). (Scale 1 : 8.) Received 1880.

This represents a passenger locomotive, built about 1875, for the Erie Railroad, and is of the then typical American construction, with outside cylinders, four coupled driving wheels, and a leading bogie.

The framing is of the bar type almost universally adopted in America, where its flexibility is considered to reduce the strains due to irregularities in the permanent way. The valve chests are above the cylinders, the valves deriving their motion from a weigh shaft driven by Howe's link motion from inside eccentrics. The boiler has the wagon-topped external firebox—a

distinctive feature of American practice. The boiler is fed by an injector and also a feed pump driven from one crosshead. The tender is carried on two bogies, a large enclosed cab is provided for the driver and stoker, while, owing to the unprotected state of the railroad and the frequent occurrence of level crossings, a " cow-catcher " is fixed to the buffer beam; a large bell is carried on the boiler and a head lamp on the smokebox.

Although a working model, some of the details are not to scale, but the engine would have cylinders 15 in. diam. by 20 in. stroke, and driving wheels 56 in. diam., giving a tractive factor of 80. M.1495.

230. Model of Fairlie locomotive (working). (Scale 1 : 12.) Received 1892.

This embodies the leading features of Mr. R. F. Fairlie's arrangement patented in 1864, by which a large amount of tractive power is obtainable from a locomotive that could work on a light rail and pass round sharp curves.

The boiler is mounted on the centre of two frames, each forming a distinct engine complete in itself, but both receiving steam from the common boiler which is of considerable length, and has two fireboxes near the middle with a chimney and smokebox at each end. The engine driver stands at one side of the firebox and the fireman at the other, protection being afforded by a central cab. The frames or bogie trucks have each two cylinders and six coupled wheels, each bogie carrying one half of the weight of the boiler by a central pivot. The steam is conducted from the boiler to the cylinders by two telescopic swivel pipes and a similar arrangement conveys the exhaust to the chimneys. The valve gear is of the Walschaërts type (*see* No. 278). The gears of the two engines are coupled up, so that they are simultaneously controlled by a single reversing lever.

There are two coal bunkers and two water tanks on the side of the boiler and two additional water tanks beneath the platform. The feed is given by a direct-acting steam pump above the boiler, and two large sand boxes are carried behind the chimneys, the engine being fitted for running in either direction, so avoiding the use of turn-tables.

An engine of this type built by Messrs. Neilson & Co. for service in Mexico closely resembles this ; the cylinders were 16 in. diam. by 22 in. stroke, with driving wheels 45 in. diam., giving a total tractive factor of 250. The heating surface was 166 plus 1,647 sq. ft., the total wheel base 30·25 ft., and the rigid base in each engine only 8·25 ft. The total weight in working order was 92·2 tons.

The peculiar bridge on which the model is shown was made to demonstrate the flexibility of the wheel base and also to facilitate inspection of the model. M.2450.

231. Model of express passenger locomotive, Great Northern Railway (working). (Scale 1 : 8). Made by Messrs. Baines Bros. Received 1905. Plate VI., No. 3.

This represents the celebrated class of locomotives, with single driving wheels 8 ft. diam., designed and introduced by Mr. Patrick Stirling in 1870. These engines successfully worked the express traffic for about 30 years, but they have now been superseded on the heavier trains by more powerful coupled engines.

The engine represented, which differs but slightly from the earlier ones, was built at the Doncaster Works in 1887. It has a pair of horizontal outside cylinders, 18 in. diam. by 28 in. stroke, with driving wheels 97·5 in. diam., giving a tractive factor of 93. The steam chests pass through the frames and the valves are driven by the usual shifting link motion, controlled from the footplate by a lever and quadrant.

The boiler barrel is 48 in. mean internal diam. by 11·42 ft. long and contains 174 copper tubes of 1·75 in. diam., having a heating surface of 936 sq. ft. The firebox has a heating surface of 109 sq. ft. and a grate area of

17·75 sq. ft. The steam pressure is limited to 170 lb. per sq. in. by Ramsbottom safety valves, and the steam is collected by a perforated pipe running along the upper part of the barrel, the regulator being placed in the smokebox. The firebox crown is tied to the outer shell by screwed stays and the end plates to the barrel by diagonal stays. The feed water is supplied from the tender by two injectors and enters the back plate, being led to the centre of the barrel by an internal pipe.

The front end of the engine is carried on a bogie, whose pivot is placed behind the centre, there being no transverse motion; its wheels are 47·5 in. diam. and its wheel base 6·5 ft. The rear end is supported by a trailing axle with wheels 55·5 in. diam. and the driving axle is fitted with helical springs. A vacuum cylinder beneath the footplate applies the brake blocks to the driving and trailing wheels.

The engine has a wheel base of 22·92 ft., and an overall length of 29·75 ft. Its weight in working order is 45·15 tons, of which 17 tons rest on the driving wheels. The tender in use in 1887 had six wheels 49·5 in. diam., and carried 2,900 gal. of water and 5 tons of coal, its weight being 33·4 tons. M.3419.

232. Model of goods locomotive, North London Railway. (Scale 1 : 24.) Lent by E. A. Forward, Esq., 1902.

This represents a class of six-coupled tank locomotives designed by Mr. J. C. Park in 1879, and subsequently constructed at the Bow Works as the standard goods engine of this suburban line.

The engine has horizontal outside cylinders, 17 in. diam. by 24 in. stroke, and steel-tired cast iron wheels 52 in diam., so that the tractive factor is 133. each crosshead works on a single guide bar arranged above it, and the driving crankpin, which carries two coupling rod ends as well as the connecting rod end, side by side, is 9·5 in. long. The valve gear is of the usual shifting link type, but the valve rods are bent to clear the leading axle, and are suspended from the frame by links which replace the more usual guides.

The boiler shell is of steel and the barrel, which is 49 in. diam., and 9·7 ft. long, contains 192 steel tubes 1·75 in. external diam., and 0·095 in. thick. The firebox is of copper and has a grate area of 16·3 sq. ft. and 81 sq. ft. of heating surface, while the tube surface is 876 sq. ft. The working pressure is 160 lb. per sq. in., and is limited by a Ramsbottom double safety valve; a steam dome is provided, and within it the regulating valve is arranged. The water is carried in a pair of side tanks, having a capacity of 956 gal., and the boiler is fed by two Gresham injectors. The bunker, which holds 1·25 tons of coal, is at the rear of the footplate and enclosed by the cab. A screw brake is provided which applies wooden blocks to the driving and trailing wheels only; sand boxes are fitted to the leading and trailing wheels.

The weight of the engine, complete in working order, is 44 tons, and this is equally distributed over the three axles. The wheel base is 11·33 ft., and the engine easily passes round curves of 5 chains radius; the overall length is 27·8 ft.

Photographs of the standard goods and passenger engines of this line are shown near. M.2313.

233. Lithographed drawings of locomotives fitted with Joy's valve gear. Lent by Messrs. David Joy and Son, 1901.

One drawing shows a four-coupled bogie engine for the Midland Railway, built at Derby in 1885. It has inside cylinders 19 in. diam. by 26 in. stroke, and driving wheels 84 in. diam., giving a tractive factor of 112. The boiler has a heating surface of 1,122 sq. ft. and a grate area of 17·5 sq. ft. The weight in working order is 42·8 tons.

The other drawing shows a four-coupled tank engine with a radial axle at each end, built at the Stratford Works of the Great Eastern Railway in 1885. It has inside cylinders 18 in. diam. by 24 in. stroke, and driving wheels 64 in.

diam., giving a tractive factor of 121. The boiler has a heating surface of 1,054 sq. ft. and a grate area of 15·43 sq. ft. The weight in working order is 51·9 tons.

234. Photographs of American locomotives. Presented by Messrs. Burnham, Parry, Williams & Co., 1890.

These show four typical American locomotives, as made at the well-known Baldwin Locomotive Works which were established at Philadelphia in 1831, and illustrate types used for four different classes of service; the dimensions and leading particulars are attached to each. M.2354.

235. Photographs of locomotives. Presented by Messrs. Neilson & Co., 1890.

This is a series of twenty photographs, together with the leading dimensions and particulars, of engines supplied for working the traffic in various parts of the world. M.2347.

236. Photographs of Russian locomotives. Presented by David Joy, Esq., 1896.

These three engines have outside cylinders, and show very clearly the arrangement of the Joy valve gear with which they are fitted.

One engine has six wheels, all coupled; it weighs 34 tons empty, and 38 tons in working order. The steam pressure is 132 lb. per sq. in., the heating surface 1,313 sq. ft., the diameter of the cylinders 18·1 in., the stroke 24 in., the diameter of the wheels 55 in., and the tractive factor 143.

The second engine has six wheels coupled and a four-wheeled bogie; the tender is on two four-wheeled bogies. The total weight of the engine empty is 52·7 tons and 58 tons in working order. The diameter of the driving wheels is 72 in., the steam pressure 147 lb. per sq. in., and the heating surface 1,661 sq. ft. The cylinders are compound and have a common stroke of 25·6 in.; the diameter of the high pressure cylinder is 19·7 in., while that of the low pressure is 28 in.

The third is a four wheel coupled engine with a leading four-wheeled bogie; it weighs 46 tons empty and 50·8 tons in working order. The diameter of the driving wheels is 78 in., the steam pressure 147 lb. per sq. in., and the heating surface 1,571 sq. ft. The cylinders are compound with a common stroke of 25·6 in.; the diameter of the high pressure cylinder is 18·1 in., and that of the low pressure 26·4 in.

The large head lights and more complete protection for the drivers are required by the local conditions; there is also a complete outside hand-rail right round the sides and front of the engine. M.2927.

237. Model of London and North Western Railway compound locomotive (working). (Scale 1 : 6.) Received 1896.

This shows a compound locomotive arranged on the system introduced by Mr. F. W. Webb in 1881, but the engine represented is of a later type, known as the "Dreadnought" class, and was shown at the Inventions Exhibition in 1885.

The distinctive feature of Mr. Webb's arrangement is that the steam from the boiler first enters a pair of outside high pressure cylinders acting on the trailing axle, while the exhaust from both of these cylinders passes into a single low pressure cylinder acting on a separate axle. This gives the reduced temperature ranges within the cylinders that result from compounding, and also the advantage of four driving wheels without employing coupling rods. When starting it is arranged that the engine can work non-compound, the

exhaust from the high pressure cylinders passing directly into the blast pipe, and reduced boiler steam being supplied to the low pressure cylinder.

The high-pressure cylinders, 14 in. diam., are arranged outside the frames between the leading and middle wheels, with long piston and connecting rods, so that they can drive the crankpins on the trailing wheels. The low pressure cylinder, 30 in. diam., is on the centre line and under the smokebox, and acts on a single crank bent in the central axle. The four driving wheels are each 75 in. diam., the stroke of each cylinder is 24 in. and the area of the single low-pressure cylinder is 2·3 times the combined areas of the two high pressure cylinders. The valve chests of the high pressure cylinders are beneath them, and that of the low pressure is above the cylinder. The valves are all driven by Joy's gear; for the outside cylinders the reversing guides are formed in pairs of circular discs, while for the inside cylinder these guides are formed in a cast steel rocking-shaft. Both gears are reversed simultaneously from the platform by a single lever, but arrangements are provided for separate adjustment when desirable.

The leading wheels are 3 ft. 9 in. diam., and are carried in Webb's radiating axleboxes, an arrangement by which on entering a curve the lateral displacement of the wheels causes an angular movement of the axle owing to the boxes being carried in a curved guide path. The rigid wheel base is 9 ft. 8 in. and the total wheel base 18 ft. 1 in.

The boiler is of steel with a copper firebox, and has a water bottom below the fire bars with a small ash door in it, and a front ashpan door and damper. The grate area is 20·5 sq. ft., and the total heating surface 1,400 sq. ft. The working pressure is 175 lb. per sq. in., but a relief valve prevents the steam to the low pressure cylinder exceeding 80 lb. The feed water is supplied by an injector on either side of the platform, delivering above the water level into a pipe which reaches to the middle of the barrel before it dips, so that the feed pipe is heated by the surrounding steam. The tender has space for 5 tons of coal but carries only 1,800 gal. of water, because it is fitted with Ramsbottom's scoop for taking up water when running (*see* No. 257).

The engine is fitted with a steam brake, having a vertical cylinder 9 in. diam., which applies the blocks to the four driving wheels and to the six wheels of the tender; a hand-worked screw gear is also provided. The weight of the engine empty is 42·5 tons, and that of the tender 12 tons. M.2936.

238. Drawings of compound engines on the North Eastern Railway. (Scale 1 : 8.) Lent by T. W. Worsdell, Esq., 1890.

Working drawings of both a passenger engine and a goods engine, on the Worsdell and Von Borries system of compounding, are shown.

In these engines two cylinders only are employed, and these are arranged within the frames. To provide room for the large low-pressure cylinder, the cylinders are cast together, and are placed at different inclinations so that they overlap. The valve motion is of Joy's radial type, and is reversed by a screw. For starting, in cases when the high-pressure slide valve is completely closed, a starting valve is provided which shuts the communication between the high and low-pressure cylinders, and at the same time allows some live steam to enter the low-pressure cylinder.

The passenger engine has cylinders 20 in. and 28 in. diam. with a common stroke of 24 in., and single driving wheels 91·25 in. diam. The boiler pressure is 200 lb. per sq. in., grate area 20·7 sq. ft., and the total heating surface 1,139 sq. ft. The weight of the engine in working order is 46·67 tons. The slide valves are arranged on the outside of the cylinders in chests that come through the frames.

The goods engine has cylinders 18 in. and 26 in. diam., with a common stroke of 24 in., and driving wheels 61·25 in. diam., with three axles coupled by external rods. In this engine the slide valves are arranged above the cylinders. The grate area is 17·23 sq. ft., and the total heating surface 1,136 sq. ft. M.2330.

239. Model of express locomotive of the London and South Western Railway (working). (Scale 1 : 8.) Made by Messrs. T. & C. J. Coates, 1896 and 1899. Plate VI., No. 4.

The engine and tender represented were designed and constructed at Nine Elms in 1890, by Mr. W. Adams, for working the express passenger traffic on the London and South Western Railway.

The cylinders are 19 in. diam. by 26 in. stroke, and act on four coupled driving wheels 85 in. diam., exerting a tractive effort of 110 lb. per lb. of effective mean pressure in the cylinders. Each piston rod is guided by a single bar guide arranged vertically over it, and in some engines of this class the piston rod was extended through the cover as a tail rod. The valve gear is of the usual shifting link construction, giving a cut-off varying from 75 per cent. with full gear to 17 per cent. in usual running condition; it is controlled from the footplate by a reversing screw. The regulator or main steam valve is of the vertical sliding type, and is arranged in a steam dome; at its back is a smaller valve which, opening first, reduces the frictional resistance of the main one.

The boiler shell and the external firebox are of mild steel, but the internal firebox is of copper. The tubes are of brass, 1·75 in. outside diam., and 240 in number. The grate area is 18 sq. ft., firebox surface 122 sq. ft., and tube surface 1,244 sq. ft. To insure complete combustion the firebox is fitted with a brick arch and a deflector. The grate bars are of cast iron in two lengths. The blast pipe is of Mr. Adams's "vortex" construction with an area of 14 sq. in. (*see* No. 260). The safety valves, loaded to 175 lb. per sq. in., are of Ramsbottom's double type, with an easing lever extending to the cab. The feed water is supplied from the tender by two injectors, and the engine is fitted with a steam and an automatic brake. The front of the engine is carried on a four-wheeled bogie, with wheels 45·75 in. diam.; the engine and bogie frames are of mild steel plate. The springs of the driving and trailing axles are connected by equalising levers. The total weight of the engine in working order is 48·75 tons.

The tender is carried on six wheels and has double frames with outside bearings; the wheel base is 13 ft. and the wheels are 45·75 in. diam. The brake of the tender is applied by a vertical steam cylinder or by a screw, the screw rod rising in its guides when the brake is forced on by steam pressure. The water tank has a capacity of 3,300 gal.; it is fitted with vertical and horizontal tie-bars and angles to give the necessary rigidity, while the supply orifice is provided with a deep strainer which acts as a baffle plate in preventing the upward splash of the water. The tender is coupled to the engine by a central draw-bar and two loose side links, and here there are also two special buffers; at the front end of the tender is a sand box and tool chest, also a hinged door for closing the opening through which the coal from the top of the tender is raked on to the footplate. The weight of the tender empty is 14·3 tons, and it carries 3 tons of coal and 14·7 tons of water.

The total weight of the engine and tender in working order is 80·75 tons, and the normal weight of the train behind them is about 230 tons. M.2926.

240. Photographs and drawings of tank locomotives. (Scale 1 : 32.) Presented by T. Hurry Riches, Esq., 1898 and 1908.

The earlier of these engines were designed by Mr. Riches in 1890 for the Taff Vale Railway.

The passenger engine has inside cylinders 17·5 in. diam. by 26 in. stroke, and four coupled wheels 63 in. diam., giving a tractive factor of 127. There is a leading four-wheeled bogie, and a pair of trailing wheels with their axle in radiating boxes. The boiler has 19 sq. ft. of grate, and 1,042 sq. ft. of heating surface; the working pressure is 160 lb. The tank carries 1,500 gal. of water and the bunker 1·5 tons of coal. The weight of the engine empty is 45 tons, and in working condition 57 tons.

The mixed-traffic engine has similar cylinders and driving wheels; it is however, six coupled, and has a radiating trailing axle, but no bogie. Its weight empty is 52 tons, and 64 tons when full.

The later photograph shows a mixed traffic engine, designed by Mr. Riches in 1908. It has inside cylinders 17·5 in. diam. by 26 in. stroke, and six coupled wheels 54·5 in. diam., giving a tractive factor of 146. There is a radiating trailing axle with wheels 37 in. diam. The boiler has a heating surface of 1,301 sq. ft., of which the firebox has 107 sq. ft. The grate area is 21 sq. ft. M.3027 and 3588

241. Photograph of American express locomotive. Presented by Harold Edwards, Esq., 1899.

This shows the leading features of the modern American locomotive, in which the bar frame and outside cylinders with valve chests above them are almost invariably adopted; the front of the engine is fitted with a powerful track clearer or cow-catcher, and the large headlight and bell are added on account of the railroad not being completely enclosed.

The engine represented, No. 999 of the New York Central and Hudson River Railroad, was shown at the Chicago Exhibition in 1893, and was stated to have travelled a distance of one mile in 32 sec.; this would be at the rate of 112·5 miles an hour. It has two cylinders 19 in. diam. by 24 in. stroke, and driving wheels 86 in. diam., giving a tractive factor of 100; there are four coupled driving wheels, and a leading four-wheeled bogie with wheels 40 in. diam. The boiler has 260 tubes, 2 in. diam. and 12 ft. long, giving nearly 1,700 sq. ft. of surface, while the heating surface in the firebox is 233 sq. ft. The total heating surface is nearly 2,000 sq. ft. and the grate area 30·7 sq. ft. The inside diameter of the chimney is 15·25 in., and its top is 14·8 ft. above the rails. In working order the weight of the engine is 55·3 tons and that of the tender 35·7 tons, the total running weight of engine and tender being 91 tons. M.3046.

242. Drawing of Baldwin locomotive. (Scale 1 : 16.) Presented by Clement E. and C. Stretton, Esqs., 1900.

This is a passenger locomotive on the Vauclain system of compounding, fitted with the extended firebox introduced in 1878 by Mr. J. E. Wootten for burning anthracite coal. It was built at the Baldwin Works in 1893, for the Philadelphia and Reading Railroad, and has attained a speed of 82 miles an hour.

On each side there is a pair of cylinders, 13 in. and 22 in. diam. by 24 in. stroke, with a common crosshead and connecting rod; there are four coupled driving wheels 78 in. diam., while the smaller wheels are 48 in. diam.

The boiler barrel is 57·5 in. diam. and contains 324 tubes 1·5 in. diam. by 10 ft. long; the firebox is 9·5 ft. long by 8 ft. wide, with a grate area of 76 sq. ft., and has 173 sq. ft. of heating surface, the total heating surface of the boiler being 1,435 sq. ft. Owing to the non-flaming character of the fuel employed, firebox surface has to be chiefly relied on, and an exceptional area of grate is necessary; these requirements are met by raising the grate above the level of the trailing wheels and by spreading it to the full width of the engine. The grate surface is formed by water-tubes and firebars alternately, and there is a separate combustion chamber. The firing platform is at the end of the boiler, but the driving cab is arranged on the sides of the barrel. The total weight of the engine in working order is 58·8 tons. M.3107.

243. Photographs of Winby's locomotive. Presented by Messrs. R. and W. Hawthorn, Leslie & Co., 1893.

Three views are shown of the engine "James Toleman," designed by Mr. F. C. Winby, and constructed in 1893 by Messrs. Hawthorn, Leslie & Co. It has two inside cylinders 17 in. diam. by 22 in. stroke, and two out-

side cylinders 16·5 in. diam. by 24 in. stroke; the total tractive factor is therefore 143·3. There are two pairs of driving wheels each 90 in. diam., and no coupling rods, as each pair of cylinders drives one axle. The boiler is peculiar, the barrel not being circular, and the grate extending much further forward than the crown of the fire-box, but the grate area is 28 sq. ft., and the total heating surface 2,000 sq. ft.; the boiler pressure is 175 lb. per sq. in. The total weight in working order is 61 tons. M.2529A.

244. Model of express passenger locomotive of the North British Railway. (Scale 1 : 16.) Lent by R. St. J. Willans, Esq. 1902.

This represents a class of four-coupled bogie locomotives designed about 1895 by Mr. Matthew Holmes, and built at the Cowlairs Works, Glasgow.

The engine has horizontal inside cylinders 18 in. diam. by 26 in. stroke and driving wheels 84 in. diam., thus giving a tractive factor of 100. The valves are placed between the cylinders and worked by the usual shifting link reversing gear controlled from the left hand side of the cab by a vertical screw.

The boiler barrel is 53·5 in. diam. by 10·3 ft. long, and contains 238 tubes 1·75 in. diam. The total heating surface is 1,266 sq. ft., of which the firebox forms 118 sq. ft., and the grate area is 20 sq. ft. The working pressure is 150 lb., and it is limited by a pair of safety valves placed on top of the dome and directly loaded by springs.

The front of the engine rests on a bogie having four wheels 42 in. diam.; the total wheel base of the engine is 22·42 ft., of which 9·33 ft. is rigid. The engine is fitted with the Westinghouse brake applied by means of cylinders suspended between the driving and trailing wheels. The weight of the engine in working order is 46·5 tons, of which 31 tons rest on the coupled wheels.

The tender is mounted on six wheels 48 in. diam. with a 12 ft. wheel base; it has outside frames and carries 2,500 gal. of water, while its weight in working order is 32 tons. The total weight of engine and tender in working order is 78·5 tons and the overall length 52·7 ft.

In front of the model is shown a grooved pulley which is used in connection with an endless wire rope employed in assisting trains up the incline from Queen St. station to Cowlairs. M.3244.

245. Print of American-built locomotive for the Midland Railway. Presented by C. E. Stretton, Esq., 1899.

In 1899 considerable sensation was caused by some of the English railway companies ordering locomotives from America, owing to a great increase of the traffic having created a sudden demand for more motive power than the existing manufacturing arrangements on this side of the Atlantic were, under exceptional circumstances, able to meet. The action was not unprecedented, because in 1840 several American locomotives were imported for use on the Birmingham and Gloucester Railway (*see* No. 215), and in our Colonies a considerable number of American engines have long been used.

The engine represented is the first of a batch of thirty ordered from the Baldwin Locomotive Works for the Midland Railway Co., and it generally represents American practice with only slight modifications to meet English requirements. The engine is of the "Mogul" type with outside cylinders 18 in. diam. by 24 in. stroke and six coupled wheels 60 in. diam., so that its tractive factor is 129; the leading wheels are 33 in. diam. and are carried in a pony frame. The rigid wheel base is 14·75 ft. and the total wheel base 22·17 ft. The framing is of the American bar type, and the cab gives much more protection from the weather than the usual English construction; the slide valves are balanced and are driven by the ordinary link motion, through the intervention of rocking shafts.

The boiler shell is 56 in. diam. and of 0·625 in. steel plate; the firebox and stays are of copper. There are 263 tubes 1·75 in. diam., giving 1,247 sq. ft. of heating surface, and the total heating surface is 1,372 sq. ft.; the grate area is 16·6 sq. ft. and the working pressure 180 lb. The tender is carried on two four-wheeled bogies and has a capacity of 3,000 gal. The weight of the engine is 44·75 tons and that of the engine and tender 80·15 tons. M.3087.

246. Drawing of express locomotive of the London and South Western Railway. (Scale 1 : 12.) Lent by Messrs. Dubs & Co., 1901.

This is an example of a class of express locomotive designed by Mr. D. Drummond in 1898, and built by Messrs. Dubs & Co. It has inside cylinders 18·5 in. diam. by 26 in. stroke, driving four coupled wheels 79 in. diam., so that its tractive factor is 1·12.

The slide bars, of which there are four to each cylinder, are entirely supported by a central spectacle plate, which also contains the guides for the valve rods. The valves, which work in a single steam chest between the cylinders, are each made in two parts placed side by side, but have separate ports, and the exhausts of the lower ones pass downward and round the outside of the cylinders. The valve gear is of the usual shifting link type, but is reversed by a steam cylinder checked by an oil cataract and controlled by a small hand lever in the cab.

The boiler barrel is 4·5 ft. diam. by 10·5 ft. long, and contains 280 brass tubes 1·5 in. external diam. The internal firebox is of copper, and has a curved roof supported by bolts from short brackets suspended from girders riveted to the external crown. The upper portion of the fire space of the box is fitted with an arrangement of water tubes, patented in 1897 by Mr. Drummond, in which straight solid-drawn steel tubes 2·75 in. external diam. and 0·125 in. thick are employed. These are arranged transversely in two groups, the front one of thirty-six tubes and the back one of twenty-five, inclining in opposite directions at 5 deg. with the horizontal. Their ends are specially expanded into the firebox plate, and opposite the ends of each group are large inspection holes through the firebox shell, closed by hinged doors bolted to cast steel seats and strengthened by internal stays passing through some of the tubes from door to door. These water tubes present 165 sq. ft. of heating surface, while that of the firebox plating is but 148 sq. ft.; the total heating surface in the boiler is 1,500 sq. ft. and the grate area 24 sq. ft.; the working pressure is 175 lb. per sq. in. The smoke box is fitted with Mr. Drummond's spark arrester, which consists of a chimney tube, extending down to the top of the blast pipe and having openings in it at the sides and front, into which the gases are directed by baffle plates. The feed water, which is supplied by two injectors at the side of the ashpan, is passed through pipes in the smokebox before entering the boiler.

The engine is supported at the front end by a bogie having four wheels 48 in. diam. at 6·5 ft. centres; the rigid wheel base of the engine is 10 ft. and its total wheel base 23·25 ft. while its weight is 50·4 tons, of which 35·4 tons are carried by the coupled wheels.

The tender has six wheels 48 in. diam. and a wheel base of 14 ft., but some of these engines are provided with tenders carried on double bogies; the capacity of the tender is 3,500 gal. of water and 4 tons of coal.

The total weight of engine and tender in working order is 91·1 tons, and the overall length is 56 ft. M.3211.

247. Model of compound locomotive, Western Railway of France (working). (Scale 1 : 10.) Made by M. P. Regnard. Received 1903. Plate VI., No. 5.

This represents a powerful passenger locomotive designed by M. Clerault and constructed at the Batignolles works of the railway company in 1901.

It has four cylinders, six coupled wheels and a leading bogie arranged in a manner introduced in 1885 by M. de Glehn and modified in 1891 by M. du Bousquet.

The engine is of the compound type, as the steam from the boiler first enters a pair of outside high-pressure cylinders acting on one axle and is then exhausted into a pair of low-pressure cylinders acting on a separate axle which is, however, coupled to the first. The cranks of the adjacent high and low-pressure cylinders are placed at 180 deg. with each other, so that the reciprocating masses move in opposite directions and thus nearly balance their inertia stresses while the rotating masses are completely balanced by weights in the wheels. Each cylinder is provided with a separate valve gear, and there are additional starting valves by which the engine can be worked non-compound, the exhaust from the high-pressure cylinders then passing directly into the blast pipe, while reduced steam direct from the boiler is supplied to the low-pressure cylinders. By these arrangements the economy due to compound working is obtained, with good balancing, while, owing to the reduction in the stresses through the work done being divided over four cylinders, it is claimed that the increased amount of mechanism entails no extra wear.

The high-pressure cylinders, 13·77 in. diam., are arranged outside the frames immediately in front of the coupled wheels, and act on the crankpins of the second pair of these wheels; the low-pressure cylinders, 21·56 in. diam., are placed between the frames under the smokebox and act on a crankshaft carrying the leading pair of coupled wheels. The low-pressure cylinders with their valve chest and the boiler cradle are in one casting secured between the frames, while the external high-pressure cylinders are stayed together between the frames by a special casting which also assists in carrying the guide bars. The stroke of both cylinders is 25·2 in. and the area of the low-pressure cylinder is 2·47 times that of the high-pressure; the driving wheels are all coupled and 76·4 in. diam.

The valve chests of all the cylinders are placed above them, those of the low-pressure, however, inclining outward; the valves are of the ordinary flat type and those of the inside cylinders are driven by the Walschaërts motion, in which a single eccentric is used for each cylinder, while those of the outside cylinders are driven by the same gear, but with a return crank in place of the eccentric; these gears can be linked up either together or separately by means of a screw reversing gear.

The valves for separating the high and low-pressure cylinders when starting are placed on the high-pressure exhaust pipes and are actuated by a small compressed air cylinder beneath the boiler barrel, while the steam pressure in the low-pressure chest is limited by a relief valve to 85 lb. per sq. in., the boiler pressure being over 200 lb.

The bogie has four wheels, 37·8 in. diam., with a wheel base of 6·56 ft. and is arranged to permit of sliding lateral displacement. The rigid wheel base of the engine is 14·11 ft. and its total wheel base 26·92 ft.; the gauge of the rails is the standard 4·7 ft.

The boiler is of steel, with a copper firebox, and has a barrel 57 in. diam. by 14·63 ft. long between tube plates. The firebox is of the Belpaire type, in which the outer shell and the firebox crown are both flat and directly tied together by screwed stays, while long transverse stays connect the flat sides of the upper part of the outer shell. By this method of staying, the usual girder stays are entirely dispensed with and increased steam space is obtained. The back plate of the external firebox is directly tied to the boiler barrel by longitudinal stays, the number of which is, however, reduced by the addition of heavy stiffening ribs riveted to the flat surfaces. The boiler is provided with 113 tubes of 2·75 in. external diam., but as these are of the internally ribbed type, patented by M. J. P. Serve in 1885 (*see* No. 261), their total internal surface is 2,149 sq. ft. although their external surface is but 1,217 sq. ft. The tubes are fitted by expanding in the usual manner after the ribs have been cut away near the ends, and they are cleaned after use by a steam jet assisted by occasional scraping.

The grate slopes forward and, to facilitate cleaning, has a hinged dropping portion at the lower end operated from the footplate. The grate area is 26·4 sq. ft. and the heating surface of the firebox 131 sq. ft. There is a steam dome containing the regulator, which is of the vertical slide type with a smaller starting slide, and there are two directly loaded safety valves upon the firebox which limit the steam pressure to 213·3 lb. per sq. in. The smokebox is long and has an ash-shoot below; the blast-pipe is provided with a nozzle which is adjustable by two hinged flaps worked from the footplate. The chimney expands within the smokebox into a conical chamber, the bottom of which is formed by a large spark-arresting grating provided with an orifice for the blast.

The feed water is delivered by a pair of injectors placed on the back of the firebox; Gresham's sanding apparatus, using compressed air, is provided for the wheels, and continuous lubrication is effected by a pump driven by the valve gear. A special fitting is attached to the boiler with which the several small steam pipes are connected, thus reducing the number of holes made through the boiler shell. The total weight of the engine in working order is 62·5 tons, of which 44·3 tons are available for adhesion.

The tender has six wheels, 44·5 in. diam., spread over a wheel base of 10·5 ft., and the springs of the two rear axles are connected by compensating levers, so that the whole load is equally distributed over the six wheels. The tender carries 3,300 gal. of water and 5 tons of coal, and its weight in working order is 36·5 tons.

The coupling between the engine and tender is of the Roy construction tightened up by a ratchet on the screw; oblique cheeks are secured to the tender while the corresponding pieces on the engine form portions of a spherical surface, so that when tightened up the connection possesses flexibility while it restricts the longitudinal and lateral movements. The engine is fitted with the Westinghouse brake apparatus, and has air brakes on the six coupled wheels; the wheels of the tender are similarly fitted, but their brakes can be applied by hand if required.

The total weight of the engine and tender in working order is 99 tons, and their overall length is 56·3 ft. M.3298.

248. Photographs of Great Northern Railway locomotives. Presented by the Great Northern Railway Co., 1911.

One of these prints represents an express passenger engine of the 4–4–2 or "Atlantic" type, built in 1908, and belonging to a class introduced by Mr. H. A. Ivatt in 1903. The cylinders are 18·75 in. diam. by 24 in. stroke, and the driving wheels 80 in. diam., giving a tractive factor of 105·5. The boiler barrel contains 248 tubes of 2·25 in. diam. which provide 2,359 sq. ft. of heating surface; the firebox is spread out over the main frames to a width of 6·75 ft., and has 141 sq. ft. of heating surface and a grate area of 30·9 sq. ft. The steam pressure is 175 lb. per sq. in. The engine has a wheel base of 26·33 ft. of which only 6·83 ft. is rigid; the bogie and trailing wheels are 44 in. diam. The engine weighs 65·5 tons, 36 tons of which rest on the coupled wheels. The tender carries 3,670 gal. of water and 5 tons of coal. The total weight of engine and tender in working order is 106·4 tons, and the overall length is 57·85 ft.

The other print represents a class of four-coupled bogie passenger engines built to the designs of Mr. H. A. Ivatt in 1911. The cylinders are 18·5 in. diam. by 26 in. stroke, and the driving wheels 80 in. diam., giving a tractive factor of 111. The boiler is fitted with the Schmidt superheater, which has a heating surface of 258 sq. ft., while the ordinary tube surface is 852 sq. ft.; the firebox has 120 sq. ft. of heating surface, and a grate area of 19 sq. ft. The steam pressure is 160 lb. per sq. in. The engine has a wheel base of 22·12 ft. of which 9 ft. are rigid; its weight is 53·3 tons, 35·5 tons of which rest on the coupled wheels. The tender is fitted with water pick-up apparatus, and carries 3,500 gal. of water and 6·5 tons of coal. The total weight of engine and tender in working order is 96·4 tons, and the overall length is 52·94 ft. M.3929 and 3930.

249. Photographs of locomotives. Lent by the Great Western Railway Co., 1911.

This series shows twelve modern locomotives employed on this line. Six types of express passenger engines, two types of passenger tank engines, and four types of goods engines are shown. All are fitted with superheaters, and the principal dimensions are given on each photograph. M.3958–68.

250. Photographs of short motor train. Presented by T. Hurry Riches, Esq., 1908.

These photographs show an arrangement now being adopted where the traffic is somewhat heavier than can be provided for by rail motor cars consisting of a single vehicle.

The train shown was constructed for the Taff Vale Railway in 1908; it consists of two cars of the type usually adopted, with an ordinary tank locomotive placed between them; arrangements are made, however, by which the train can be driven in either direction, so that terminal shunting is avoided. A driver's compartment is formed at either end, and is provided with fittings for operating the engine regulator and whistle and the automatic and hand brakes. The fireman attends to the boiler and the reversing gear. The locomotive used was built in 1884; it has outside cylinders 16 in. diam. by 24 in. stroke, and four-coupled wheels 63 in. diam., giving a tractive factor of 97·5; it has a bogie at the leading end. The carriages are supported on two four-wheeled bogies, and they have accommodation for first and third class passengers. M.3588.

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251. Model of Fell centre rail locomotive (working). (Scale 1 : 16.) Made from drawings prepared in the Museum, 1904.

The use of a central rail and horizontal gripping wheels to increase the adhesion of a locomotive running on smooth rails was first proposed and patented in 1830 by Messrs. C. B. Vignoles and J. Ericsson, while the system was re-invented in 1847 by Mr. G. E. Sellers, who tried it practically in America. The project was revived, however, during the construction of the Mont Cenis tunnel, when Mr. J. B. Fell proposed that a railway on the "central rail" system should be built over the pass, and in 1863–9 he secured patents for such locomotives. After experiments had been carried out on the Cromford and High Peak Railway and at Mont Cenis, the line was constructed and opened in 1868, but it was not financially successful, and its life ended on the opening of the tunnel in 1871. The railway was 48 miles in length, laid along the public road to a gauge of 3·61 ft. (1·1 m.), having a maximum gradient of 1 in 12 with a minimum radius of curvature of 2 chains; the central rail was laid on all gradients steeper than 1 in 25. The system was afterwards tried in Brazil. In 1879 an incline of 1 in 15 was constructed in New Zealand and successfully worked.

The model represents the framework and gearing of one of the Mont Cenis engines built in 1867 by Messrs. Gouin & Co., Paris; it is shown mounted on a gradient of 1 in 12.

The engine was carried on four-coupled wheels 28 in. in diam. with a wheel base of 7·08 ft. There were two horizontal cylinders 16 in. diam. by 16 in. stroke, fixed between the frames in the usual way, with the valve chests between them. The valves were driven by outside eccentrics, link motion, and rocking shafts. The tractive factor was 146·3. At the middle of the engine, between a pair of transverse stays, were situated two sliding frames, one on each side of the centre line; each of these carried two vertical shafts, having at their upper ends overhung cranks, while to their lower ends were fixed the horizontal wheels, 28 in. diam., which were pressed inward so as to grip the central rail, by means of springs and cross-beams actuated by a right and left hand screw operated from the footplate. The shafts on

each side of the central rail were coupled by rods at the top and bottom, and were directly driven by the pistons through connecting rods moving in a horizontal plane, while the motion was communicated to the carrying wheels through rocking shafts and levers which drove outside connecting rods attached to crank pins in the wheels. In later engines, however, it was found necessary to couple the horizontal wheels on opposite sides of the central rail by linkwork or spur gearing, so as to keep them in correct phase with one another. The boiler had a barrel 3 ft. diam., and 9·33 ft. long, with a heating surface of 654 sq. ft. and a grate area of 13·5 sq. ft.; the steam pressure was 120 lb. per sq. in. When descending inclines the engine was retarded by brake blocks on the carrying wheels and also by means of slipper blocks gripping the central rail.

The weight of the engine in working order was about 20 tons, while a similar pressure could be applied to the central rail, thus doubling the adhesion; in general working the engine hauled a load equal to its own weight up a gradient of 1 in 12 at a speed of 10 miles an hour. The double-headed central rail was laid on its side and supported on chairs formed of bent wrought iron bars which were bolted to longitudinal sleepers laid upon and secured to the transverse ones. M.3374.

A photograph of one of the engines used on the New Zealand line is shown in No. 235.

252. Model of Riggenbach rack locomotive (working). (Scale 1 : 16.) Made from drawings prepared in the Museum. 1904.

The rack and pinion as a means of locomotive haulage was patented in 1811 and used in 1812 by John Blenkinsop (*see* No. 186). In 1852 the system was revived with a central rack and applied to an incline of 1 in 16·5 at Madison, U.S.A. In 1857 Mr. S. Marsh proposed a similar line with a maximum gradient of 1 in 3 at Mount Washington, U.S.A., and this was constructed in 1869. The system was taken up in Europe by Mr. N. Riggenbach, who patented improved appliances in 1862; in 1870 he constructed the Rigi railway in Switzerland, which has a maximum gradient of 1 in 4; this was followed by several others, one of which runs up the Kahlenberg, near Vienna. This line, which was constructed in 1874, was laid to a gauge of 4·71 ft. and had a maximum gradient of 1 in 10; the ladder rack was laid midway between the rails. The model represents the framework and gearing of one of the locomotives built for this line at the Swiss Locomotive Works, Winterthür. It is shown mounted on a 10 per cent incline.

The engine was carried on four wheels, 26 in. diam., with a wheel base of 10·17 ft. There were two horizontal outside cylinders 13 in. diam. by 17·72 in. stroke, which drove a countershaft having a pair of pinions fixed on it; below this was a shaft carrying a toothed wheel which geared with the rack, and to each side of it was bolted a wheel gearing with the pinion above. The tractive factor was 173. The boiler was of the ordinary locomotive type with a heating surface of 582 sq. ft. and a grate area of 10·6 sq. ft.; the steam pressure was 132 lb. per sq. in.

The engine, with its chimney at the lower end, pushed the carriages up the incline, there being no couplings. The descent was regulated by three methods of braking: (*a*) by a strap brake on one of the crank discs, (*b*) by a toothed pinion on the back axle gearing with the rack and fitted with drums and brake blocks, (*c*) by the compression in the cylinders of air from the outside, drawn through the exhaust ports and expelled through a special regulating valve. Guards were provided to prevent derailment. The engine carried 220 gal. of water in tanks and 25 cwt. of coal in bunkers; its weight in working order was 19·44 tons and its ordinary load 42 tons.

The permanent way consisted of flat-footed rails weighing 40 lb. per yd., spiked to transverse sleepers. The rack had a pitch of 3·72 in., the teeth being formed of wrought iron bars of trapezoidal section with oval ends riveted into the webs of a pair of 4 in. by 2·4 in. channel irons, placed back to

back 5 in. apart. The rack was in lengths of about 10 ft. joined by fish plates and bolted to the sleepers: its weight was 111 lb. per yard. M.3375.

An adjacent print shows the complete engine.

253. Model of Abt rack locomotive (working). (Scale 1 : 16.) Made from drawings prepared in the Museum, 1904.

The Riggenbach ladder rack as used on most of the early mountain railways had several defects, and to overcome these Mr. R. Abt patented in 1882 an improved form of rack consisting of narrow rectangular bars having teeth cut in them, and placed vertically on chairs. These bars were arranged in two or three lines near together with the teeth stepped, and a pair of stepped pinions on the locomotive, out of phase with one another, geared into them, thus ensuring smoothness of motion. The first railway on this system was constructed in 1884–6 at Blankenburg in the Harz Mountains and the system has since received wide application. In 1894–6 a tourist line was constructed on Mount Snowdon; it is 4·67 miles long with a rise of 3,140 ft., its average gradient being 1 in 7·83 and the maximum gradient 1 in 5·5; the gauge is 31·5 in. and the minimum curve is of 4 chains radius. The model represents the framework and gearing of one of the locomotives built at the Swiss Locomotive Works, Winterthür, for use on this line, together with the permanent way on a gradient of 1 in 5·5.

The engine is carried on 6 wheels; the four leading ones are 25·71 in. diam., running loose on their axles; the trailing wheels, 20·47 in. diam., are arranged on a Bissel truck; the rigid wheel base is 4·43 ft. and the total 9·85 ft. There are two horizontal outside cylinders, 11·81 in. diam. by 23·62 in. stroke, placed above the footplate midway along the engine, with the valve chests above them. The piston rods are continued forward to the crossheads and the motion is communicated to cranks on the central axle through connecting rods and rocking levers pivoted low down on the frame. The two leading axles are coupled by rods and each carry a double pinion gearing with the rack; these consist of toothed rings, connected with discs forged solid with the axle by means of internal springs allowing a slight circumferential movement, thus compensating for any irregularities in the rack teeth. Each pinion has fifteen teeth and a pitch diameter of 22·56 in., the teeth of one pinion ring being opposite the spaces of the other. The tractive factor is 146. The pinions are held in position laterally by grooved brake drums on each side bolted to the axle discs. The engine frames are outside the wheels and are strongly braced by vertical and horizontal cross stays; springs are provided at the driving and trailing wheels only. The boiler has a heating surface of 397 sq. ft. and a grate area of 10 sq. ft.; its axis is inclined at 1 in 11 to the rails; the steam pressure is 200 lb. per sq. in.

The engine pushes its load up the inclines, there being no couplings, whilst on the descent three methods of braking are available. These consist of (*a*) brake blocks gripping the drums on the driving axles, (*b*) an automatic gear which applies a steam brake to two of the drums when the speed of the engine exceeds 5 miles an hour, and (*c*) by the compression of air in the cylinders, air from outside being drawn in through the exhaust ports, compressed, and expelled through a special regulating valve. The latter method is generally used and water jets are introduced into the cylinders to cool the air. Water is carried in side tanks having a capacity of 440 gal., while the coal bunker holds 10 cwt.; the weight of the engine in working order is 17·22 tons, its load of 18·5 tons being conveyed at a speed of 4 to 5 miles an hour.

The rack bars are cut to form in one operation in a milling machine by a gang of cutters; they are 70·7 in. long, and have 15 teeth of 4·72 in. pitch and 1·97 in. depth; the thickness is 0·98 in. on gradients steeper than 1 in 9 and 0·79 in. on flatter gradients. The bars are arranged so as to break joint and are bolted at the middle and ends to rolled steel chairs, weighing 12 lb. each, which are bolted to the transverse sleepers. The rails are flat-footed and weigh 41·25 lb. per yd.; the sleepers are of steel of trough section with turned-down ends, 6 ft. long and spaced 35·45 in. apart; the rails are fastened

by clips and bolts. At intervals of 50 to 150 yd., according to the gradient, vertical iron joists, set in concrete blocks, bear against the sleepers and act as stops to prevent the track creeping down hill. M.3376.

An adjacent print shows the complete engine.

254. Model of Pilatus rack locomotive (working). (Scale 1 : 16.) Made from drawings prepared in the Museum, 1909.

The railway up Mount Pilatus, near Lucerne, Switzerland, was constructed in 1886–8. It is 2·83 miles long, and rises 5,370 ft.; the average gradient is 1 in 2·56, and the maximum 48 per cent., or 1 in 2·08. The horizontal curves have a radius of 4 chains, and the vertical ones a radius of 25 chains; the gauge of the rails is 31·5 in. (800 mm.). The gradients being so much steeper than those on previous lines worked by rack locomotives, experiments were first made to test the suitability of the ordinary vertical toothed wheel system, and it was found that the wheels rose out of gear when the load was put on. A system was therefore devised by Dr. E. Locher in which a pair of horizontal toothed wheels gear with a double horizontal rack; this arrangement may be considered as a toothed development of the centre rail system (*see* No. 251). In order to reduce weight, the engine and carriage are built on the same underframe. The model represents the framework and gearing of one of the locomotives, built at the Swiss Locomotive Works, Winterthür, for use on this line. It is shown, with its track, mounted on a gradient of 1 in 2·08.

The underframe is carried on four flangeless wheels, 15·75 in. diam., with a wheel base of 15·92 ft. The engine is placed at the lower end and has two horizontal outside cylinders, 8·62 in. diam. by 11·75 in. stroke, with the valve chests below them. The connecting rods drive a horizontal crankshaft, upon the middle of which a spur pinion is fixed, and this, by a spur wheel and two pairs of bevel wheels, drives the vertical shafts that carry at their lower ends the toothed driving wheels. The vertical bevel wheels are not rigidly connected with the spur wheel, but have a slight relative motion to give a differential action when passing round curves. The driving wheels have 15 teeth and a pitch diameter of 16·1 in.; they are fitted with guiding rings below, equal in diameter to the pitch circles, and these roll upon the central rail which supports the rack, and also prevent the wheels from rising out of gear. The gear ratio is 3·8 : 1 and the tractive factor is 206; no springs are fitted to the axles. At the front end of the frame is placed another pair of toothed wheels similar to the driving ones, and these are used to guide the car and also to actuate the automatic brake. The engine frames are between the wheels and are strongly braced by top and bottom plates; the central portion is used as a water tank. The boiler is of the usual locomotive type, but is placed transversely; it has a heating surface of 215 sq. ft. and a grate area of 4 sq. ft.; the steam pressure is 176 lb. per sq. in.

The normal speed of the engine is 2·25 miles an hour and, on the downward journey, is controlled by three brakes. These consist of (*a*) a hand-applied band brake on one of the engine crank discs, (*b*) a cylinder air-brake (*see* No. 253), and (*c*) an automatic brake that acts upon a drum connected with the front pair of toothed wheels by worm gearing, and which comes into action if the speed exceeds 3 miles an hour; the latter brake can also be applied by the front brakesman. Clips are fitted, embracing the running rails, to guard against derailment by wind. The water tank carries 176 gal., and the coal bunker holds 2·5 cwt. The weight of the loaded car is 10·5 tons.

The permanent way consists of flat-footed rails, in lengths of 19·7 ft., bolted to channel iron cross sleepers. The rack is formed of steel bars, 9·85 ft. long, with 35 teeth, 3·38 in. pitch and 1·1 deep, milled along each side; these are bolted to the top of a continuous saddle-shaped rail, which is itself bolted to chairs formed of channels and angles riveted to the cross sleepers. Due allowance is made for expansion. In order to prevent the track from slipping downhill, the cross sleepers are bedded on a continuous solid masonry bed, and are secured by sling bolts which pass round it. M.3589.

An adjacent print shows the complete engine.

255. Model of an electric locomotive (working). (Scale 1 : 4.) Lent by Messrs. Beyer, Peacock & Co., 1894.

This electric locomotive, patented by Messrs. R. Peacock and H. L. Lange in 1890, is designed to receive its current from a contact piece sliding on a central rail, or from an overhead conductor. The chief object of the arrangement is to dispense with spur gearing and yet keep the armatures well above the mud and dust, which, owing to the small driving wheels necessary, are found in the neighbourhood of the axles.

There are two armatures, and each is connected by two overhanging cranks and diagonal coupling rods with one of the driving axles, so that the axles are driven independently. The axle boxes slide in inclined guides, so that the pull of the coupling rods shall not be felt on the springs. The armatures are in a single magnetic circuit, and the field windings are arranged in one horizontal and two vertical coils below the platform. A screw brake is provided for stopping, but the starting levers and resistances are not shown.

The model is carried on friction wheels which can be rotated from outside the case, so that the motion of the connecting rods may be followed. M.2561.

256. Steam tramcar. (Scale 1 : 8.) Contributed by Mrs. Grantham, 1876.

Mr. J. Grantham in 1871 patented a steam car in which the machinery was below the floor and two vertical boilers were on opposite sides of the car, so as to leave a clear passage from end to end. The exhaust steam was condensed in exposed pipes; the boilers were fired by a screw conveyor; and the whole of the machinery and the brakes were controlled from either end of the car by one man.

In 1872 a car on this plan was made, 30 ft. overall and accommodating twenty inside and twenty-four outside passengers. Each of the boilers was 4·33 ft. high by 18 in. diam. and fitted with Field tubes; the grate area was only 1·2 sq. ft., while the pressure was 90 lb. The two cylinders were 4 in. diam. by 10 in. stroke and directly drove wheels 30 in. diam., so that the tractive factor was 5·33; the axles were 10 ft. centres and the total weight empty 6·5 tons. The car, after being tried successfully on a railway, was placed in 1873 on the tramline between Victoria Station and Vauxhall, but it ultimately failed owing to deficiency in boiler power and to difficulties in firing; it was, however, the first steam tramcar that worked in England.

The model shows additional features patented in 1872; the driving wheels are flangeless and the axles of the other wheels swivel, so as to render the car dirigible for use on common roads, also these wheels are loose on their axles; for use on rails there are two axles with flanged wheels which can be lowered by levers till they bear on the rails. The double gates at either end of the car are for checking the fares.

The Grantham car, after being modified by Mr. E. Woods, continued in use on the Wantage tramway till 1881. M.1935.

Locomotive Details.

257. Model of Ramsbottom's water scoop for supplying locomotives. (Scale 1 : 6.) Lent by J. Ramsbottom, Esq., 1893. Plate VI., No. 2.

This represents a locomotive tender fitted with Ramsbottom's arrangement for picking up the feed-water while a train is running, an arrangement introduced in the year 1860, on the London and North Western Railway, and now adopted on many other lines.

A cast iron trough, 440 yd. long, 18 in. wide, and 6 in. deep, cast in 6 ft. lengths and jointed with india-rubber cord, is placed between the rails and

secured to the sleepers. Between the ends of this trough the rails dip about 6 in., so that the water-lifting arrangement clears the ends of the trough but dips into it for the rest of its length.

From the bottom of the tender a large rectangular pipe passes to within 18 in. of the trough, and is provided with a continuation finishing in the form of a scoop 10 in. wide and 2 in. deep, which is carried on a horizontal axis, round which it can be rotated so as to be well clear of the road when not in use. The model shows the delivery pipe entering the floor of the tender and being there closed by a flap valve, but in practice the pipe is usually carried to the top of the tender and then turned downward, so dispensing with the use of a valve. The extra lift thus entailed is not of importance, as at a speed of 22 miles per hour the scoop picks up its full quantity of 400 gal. in passing over the trough. M.2502.

258. Model of coupling wheels for locomotives. (Scale 1 : 8.) Contributed by W. B. Adams, Esq., 1869.

This method of connecting the wheels of a locomotive, so that the adhesion due to the total weight of the engine shall be available for tractive purposes, was provisionally patented by Mr. Adams in 1855; the arrangement had, however, been patented in 1837 by Mr. J. Melling, so Mr. Adams did not proceed with it. In recent years the device has been tried on a practical scale in America; it enables wheels of different diameters to be coupled, and also gives a connection that may be temporarily made when required, even while running.

The model represents a radiating axle locomotive frame, with eight travelling wheels, of which the front four are frictionally coupled by an elevated pair of wheels pressing upon them, while the hind four wheels are similarly connected by another pair. The upper axles may be independently driven, but as here represented the central pairs of travelling wheels are to be connected by coupling rods, one pair only being directly driven. Arrangements are made for throwing any required proportion of the weight of the engine upon the elevated axles. In Melling's specification steam-moved levers were introduced for this purpose. M.1121.

259. Model of built-up crank axle. (Scale 1 : 4.) Made from information supplied by H. A. Ivatt, Esq., 1909.

This model represents a locomotive crank axle built up in the manner patented by Mr. Ivatt in 1908; by this construction flexibility is secured, the axle is balanced and renewal of parts is facilitated.

The axle has two cranks at right angles to one another and is built up of four pieces. The two outer pieces consist of a wheel seat and journal together with the outer crank web and crankpin. The inner pieces consist of a web which is extended backward at an angle of 45 deg., bent and thickened, so that the extensions of the two cranks meet and are bolted together with a tongue and groove joint; these form the balance weight. The inner ends of the crankpins are shrunk and keyed into holes in the webs, and the outer webs are hooped.

An adjacent print shows another form of this axle, in which the two central crank webs are replaced by a straight piece of shaft with end palms that are bolted to extensions of the inner crank webs so that eccentrics may be fitted. M.3716.

260. Model of Adams's locomotive blast pipe. (Scale 1 : 4.) Lent by W. Adams, Esq., 1890.

By this arrangement the exhaust steam is discharged as a hollow cylindrical jet; thereby greatly increasing the amount of surface presented to the gases in the smokebox, so that a greater exhaustive effect is produced.

The gases carried into the chimney by the external surface of the jet are gathered from the upper portion of the smokebox, as with the common form of nozzle, but the inner surface acts only on the gas drawn from the lower portion of the box and so increases the draught through the lower tubes of the boiler, which otherwise are not so active as the higher ones. M.2309.

261. "Serve" boiler tubes. Presented by Messrs. John Brown & Co., Ltd., 1904.

These boiler tubes, patented in 1885 by Mons. J. P. Serve, are provided with internal longitudinal ribs, or fins, which increase the surface for the absorption of heat from the furnace gases, while the external cylindrical surface of the tube suffices for the transmission of this heat to the wafer; the ribs also increase the rigidity of the tubes. Some experiments, with plain tubes and ribbed ones of the same diameter and length, gave an increase of 15 per cent. in the amount of water evaporated per lb. of coal in favour of the ribbed tubes; for locomotive boilers, in which they are extensively used in France, the small plain tubes have been replaced by about one half the number of "Serve" tubes of larger diameter, and it is stated that by their use a boiler may have its tubes considerably shortened, thus reducing weight, without diminishing its power or efficiency. It was also found that 1·2 sq. ft. of inner surface of ribbed tube were equivalent to 1 sq. ft. of inner surface of smaller plain tube, and that by the use of ribbed tubes the requisite surface could be provided in a locomotive boiler with fewer holes in the tube plates than would otherwise be necessary.

The specimens show different stages in the process of manufacture, which consists in preparing, by rolling, a flat plate of the required width and thickness, but having the necessary ribs projecting from its surface; this plate is then bent to cylindrical shape and a lap-welded joint formed, either by passing the tube, on a suitable mandrel, between welding rolls or under a power hammer. At each end of the tubes the ribs are cut away for some inches to allow of their being expanded into the tube plates in the usual manner.

The tubes are made of mild steel, and in sizes ranging, for land boilers, from 2·5 in. to 3 in. external diam., those for locomotives being usually 2·75 in. diam.; those shown are 2·5 in. diam., 0·125 in. thick, and have seven ribs projecting 0·5 in. M.3357.

262. Model of "Phœnix" smoke-box superheater. (Scale 1 : 4.) Received 1911.

This represents the form of waste gas superheater, for boilers of the locomotive type, patented by Mr. S. S. Macaskie in 1909, and now being used on several railways. It gives a moderate degree of superheat, the steam temperature being raised from 371 deg. F. at 160 lb. pressure to about 500 F., which is sufficient to obviate cylinder condensation, and to show a reduction in coal consumption of 20 to 25 per cent. or even more. The superheater can be fitted to any existing boiler without alteration, except to the smoke-box itself, and ordinary slide valves can be retained.

The superheater consists of two boxes or headers fixed in the lower part of the smoke-box, one on each side, parallel to the axis of the boiler. Each box is divided by longitudinal and transverse partitions forming distinct chambers, and each chamber is provided with a group of superheater tubes, passing from one box to the other round the smoke-box, their ends being expanded into the tops of the headers. The tubes at the rear end pass directly from one header to the other, while the front ones pass into a divided intermediate chamber which has a central conical passage, below the chimney and above the blast pipe, to allow the exhaust steam to pass. The steam enters at the outer front corner of one header, takes a circuitous

path from the coolest to the hottest part of the smoke-box, and leaves at the inner back corner of the other header. A baffle is fitted behind the exhaust pipe which, in conjunction with the cone over the blast nozzle, causes a good distribution of the hot gases around the superheater tubes before they pass to the chimney. The tubes are of small diameter giving a large heating surface. Doors are provided on the bottoms of the headers, and the top chamber has sloping joint faces to facilitate its removal. The upper part of the smoke-box is made detachable so that the whole superheater may be lifted out easily. M.3906.

STEAM ENGINE DETAILS AND ACCESSORIES.

These details are grouped as a separate section but many of them will be found represented in the various complete engine models already described, and to these references will be given without a repetition of the description.

Valves and Valve Gears.—The simple plug valves used in working Savery's steam pumping machine of 1698 were turned in their correct order, each about four times per minute by an attendant. Newcomen's engines were similarly worked, but as early as 1719 some had an automatic valve gear and since then all engines have been arranged to perform their own steam distribution. The Watt engines had vertical drop valves lifted and lowered by levers moved by a tappet rod, and locked in position by latches. In 1799 Murdock invented the long D valve with one flat face sliding on a face on the cylinder side through which were ports leading to the two ends; in 1800 he introduced, in place of the previous tappets and cams, an eccentric with straps for moving the valves; this invention, together with the modification of his slide introduced by Murray between 1802 and 1806, and known as the locomotive valve, have become almost universal for all but the largest engines.

Engines that were required to run at intervals in opposite directions were at first fitted with a single loose eccentric, from which the motion was conveyed to the valve stem by a notched lever. When the engine was to be reversed this notched lever was lifted out of gear, and the valves worked by hand till the eccentric engaged with a second stop corresponding with the opposite motion of the engine. The notch or "gab" was then allowed again to engage with the valve stem, so that the motion of the engine would be continued as before, but in the reversed direction. With the early locomotives, as will be seen on the "Rocket," there were two eccentrics, and two of these gab levers, since there were two cylinders, and it is recorded that at a high speed the levers on the "Rocket" were inclined to jump out of gear. In 1842 William Howe, a fitter in the employ of Messrs. R. Stephenson & Co., invented an arrangement of valve gear that was at once adopted, and still remains the most usual device for reversing an engine or for varying the rate of expansion, the latter being an equally important property of the invention. He employed a backward and a forward eccentric for each cylinder, as already used, and connected the rods of each pair by a curved link, while by a simple shaft and lever it was arranged that the link could be moved so that an adjustable amount of the motion from either eccentric could be transmitted to the valve rod. This form of link motion is generally known as Stephenson's shifting link. Sir D. Gooch introduced a link motion in which the link was held almost stationary by a swinging

lever, and the valve rod terminated in a swinging arm which could be moved into that portion of the link giving the motion required. Allan combined these two forms in his straight-link motion in which both the links and the valve rod are moved, an arrangement that somewhat reduces the vertical height required.

Egide Walschaërts in 1844 introduced a valve gear in which only one eccentric was used, but it made little progress until 1859, when the eccentric was displaced by a return crank. An identical arrangement of this valve motion was independently invented and introduced in 1849 by Edmund Heusinger von Waldegg, and hence it is sometimes known by his name. J. W. Hackworth in 1854 introduced another form of single eccentric gear, the reversal being obtained by altering the inclination of the slot in which a block, attached to the eccentric rod, works, while the valve rod is attached to the outer extremity of the eccentric rod. David Joy, in 1880, introduced a radial valve gear, the motion being derived from a lever attached to the connecting rod, and the reversal given by a slot of variable inclination as in Hackworth's gear.

With the object of obtaining a quick but easily variable cut-off a large number of so-called "expansion gears" have been introduced of the "trip" class in which the steam admission valves close when a catch under the control of the governor is released, the exhaust valves being independently worked by a separate eccentric. By these or other gears the degree of expansion of which the engine works is continuously adjusted to suit the work being done instead of the speed being controlled by throttling the steam supply.

Governors.—In the early Cornish pumping engine the interval of rest between a double stroke was determined by a balanced tank into which water was continually running from an adjustable orifice; when the tank was nearly full it automatically capsized and delivered its water in a cataract, at the same time moving the valve gear. The later "cataract" or fluid controlled gears have only a plunger which sinks at a speed determined by the extent to which a regulating valve is opened.

For regulating the speed of his rotative steam engine Watt adapted the centrifugal governor which had already been applied to the regulation of the speed or fineness of grinding of both wind and water mills. His arrangement consisted of a revolving vertical spindle carrying two dependent swinging levers provided at the lower ends with heavy metal balls, thus forming a balanced conical pendulum, the vertical angle of which would increase with the speed of rotation; by an arrangement of levers this movement of the swinging arms was transmitted to a valve in the steam pipe which throttled the supply of steam, so moderating the fluctuations of the engines under varying conditions of load. Obviously the governor did not maintain constant speed in the engine, but merely reduced the otherwise great variations that would follow an increase or diminution of the steam pressure or the resistances. The variation in fluid resistance

with an increase in speed has frequently been tried as a means for regulating the speed of engines, but up to the present time some form of centrifugal governor is the most usual arrangement. Watt's governor was a very large piece of mechanism, often running but little faster than the engine. Porter introduced the first great improvement by loading the governor with a weight which, while tending to pull down the balls, did not increase their centrifugal action. This enabled the governor to be run at a high speed, and so render it as sensitive as could be desired to any variation of the engine's speed. The modern governors all embody this principle, but frequently springs instead of weights are introduced to supply the closing power, and give the resistance required by the high speed necessary for efficient governing.

The throttle valve employed by Watt consisted of a disc placed in the steam pipe and capable of rotating with a spindle which passed across the steam pipe, and along the diameter of the disc. Such a valve is nearly in equilibrium, and therefore requires but little power from the governor to close it, but it is not very tight or convenient to construct, so that in modern governors a form of double beat equilibrium piston valve is generally adopted.

Lubricators.—Examples of lubricators for revolving shafts and general mechanism will be found grouped with shafting and pedestals, but for the steam engine, in addition to these, a special form of lubricator working under pressure is required to supply oil to the inside of the cylinder, slide valve faces, etc. This is generally done by allowing the steam to carry in with it a minute quantity of the lubricant in the form of spray which becomes distributed on the free surfaces, or it may be allowed to drop directly into the cylinder. The chief object aimed at in modern improvements in such fittings is to economise the oil as much as possible—since it has been stated that in some small engines the cost of lubrication exceeded that of the fuel.

A method of regularly introducing a small quantity of oil into the cylinder is that followed by the displacement lubricator in which condensed steam drops into the oil receptacle, so causing the lubricant to overflow into the requisite channel. An extension of this plan forms what is known as the sight-feed lubricator in which the drops of oil displaced ascend through a closed tube containing water, so that the rate of feed can be seen and the number of drops admitted per minute can be counted and adjusted.

Engine Packing.—The object of applying packing to steam-engine pistons is to prevent the passage of steam between the cylinder and piston, due to imperfect workmanship and the impossibility of making the piston work tightly in the cylinder in consequence of the friction that would thereby be produced. In early engines, with a low temperature and pressure of steam, hemp packing was found to work well enough, but with the higher temperatures of high pressure steam, metallic packing is now always used for pistons. The first attempt in this direction

was made in 1778 by Watt, who introduced pieces of anti-friction metal along with the soft packing. In 1797 the Rev. Edmund Cartwright patented complete metallic piston packing. In modern packings considerable attention is paid to the attainment of uniformity of radial pressure and to the avoidance of leakage between the sides of the rings and the piston.

For piston rods, the packing at one time generally used was in the form of woven fibrous material often mixed with plumbago, soapstone, or similar lubricant. Special arrangements of rings and springs have, however, been successfully introduced, and complete metallic packing is now commonly used for all large glands.

Condensers and Air Pumps.—Until Watt introduced the separate condenser (*see* No. 52) steam had been condensed by a jet or spray of water projected upward in a vertical cylinder, and as during the steam stroke some blowing through took place, no trouble was experienced from accumulated air. With Watt's arrangements, however, the necessity for a special pump to remove both air and water was at once seen and provided for. Watt saw also that if he could separate the cooling water from the condensed steam the size of the air pump and the power it absorbed would be reduced, and he accordingly experimented with a surface condenser in which the water was within numerous small tubes and the exhaust steam surrounding them (*see* No. 53). Difficulty in obtaining sound tubes and in fixing them led to the abandonment of the surface condenser till 1833–7 when it was successfully reintroduced and extensively manufactured by Samuel Hall. When cooling water is scarce, surface condensers are now frequently built with exposed tubes kept moist by water trickling over them. The evaporation of this external water carries off the heat so efficiently that only about one twentieth part of the water necessary with an internal circulating system is consumed. If space is available, however, the condensing water is generally cooled in large shallow ponds and sometimes the cooling is hastened by distributing the water over cooling towers so as to increase the surface exposed to evaporation. The "ejector condenser" invented by Mr. Morton (*see* No. 698) is a compact arrangement of the injector class. Dry surface condensers, composed of small tubes, have been used on the top of tramcar engines, etc, but they only save feed water and prevent annoyance from the exhaust steam; as the degree of vacuum obtainable is not worth consideration, such condensers are seldom closed to the atmosphere.

Intermediate Receivers.—These are a necessity between the cylinders of compound engines when the cranks are at right angles; it is probable, moreover, that their introduction does not detract from the efficiency of the engine, while it gives greater facility for starting, the dead centres being covered. The efficiency of the compound engine is stated to be improved by the practice of heating the steam, while in the immediate receiver, by jacketing this vessel with boiler steam, as adopted by Mr. Cowper in his "hot-pot."

263. Sectional models of steam engine slide valves (working). Made in the Museum, 1902.

This series of eight models shows various modifications that have been employed in this type of valve since its original introduction by William Murdock between 1781–6 in his models of an oscillating engine and a steam carriage (*see* Nos. 79 and 160).

As a sliding valve may continue its movement after it has closed any particular passage which it controls, it may be so arranged as to open or close other passages, simultaneously or otherwise, and thus combine the duties of several valves. Owing to this feature a single slide valve replaced the four beat valves which were originally necessary in the early double-acting steam engines, and this simplicity, combined with quietness in working, has since led to the general adoption of the slide valve in nearly all classes of steam engines.

The valves illustrated are:—long D, short D, common or locomotive, piston, double-ported, Trick's, Church's and Hackworth's, details of which will be found attached. M.3263.

264. Sectional models of steam engine slide valves for variable expansion (working). Made in the Museum, 1903.

In order to adjust the work done in steam engine cylinders to suit the variations in the load, two methods are practicable; the first and simplest is to reduce the pressure in the steam chest, by throttling, when the load is below its maximum amount; the second and more economical method is to alter the fraction of the stroke during which steam is being admitted, and leave the completion of the stroke to be performed by this steam while expanding. For this latter system of working many devices have been employed, usually involving some form of valve arranged on the back of the main valve and so actuated by adjustable gearing as to cut off the steam on its way to the main valve.

Such expansion slide valves first came into extensive use about 1840 in the locomotive, the gab reversing gears then employed not permitting of any variation in the point of cut-off; they, moreover, continued in use on locomotives in America and on the Continent for some years after the introduction of the link motion which has now so completely superseded them. For the slow running non-compound marine engines, in which a cut-off earlier than half stroke was generally required, the excessive compression given by the link motion, although advantageous for high piston speeds, was found to be inconvenient so that the separate expansion valve was generally retained until, with the use of direct-acting screw engines, the speeds increased. It was, however, on the non-reversing stationary engine that these expansion arrangements were most extensively adopted, and further developed by being rendered automatic under the control of a centrifugal governor.

A variable expansion valve usually consists of a main slide valve, controlling the admission, release, and compression; and a separate cut-off valve, working either on a separate face or on the back of the main valve, controlling the cut-off only, by shutting off steam from the main valve. The main valve is driven by an eccentric and has little lap, cutting off the steam after about 0·75 of the stroke, while the cut-off valve is driven by another eccentric set considerably in advance of the main one. The variation of the point of cut-off is effected by altering either the lap, travel, or advance, of the expansion valve, and the range of the period of admission generally provided is from 0 to 0·75 of the stroke.

The six models show the construction of the leading types of expansion slide valves that have been practically employed, and they are so arranged that they can be worked and adjusted from outside the case.

The valves illustrated are:—Back-plate, Meyer's, piston, Rider's, Hartnell's, and Paxman's, details of which will be found attached. M.3297.

265. Model of balanced slide valve. (Scale 1 : 8.) Lent by H. P. Holt, Esq., 1879.

This is a section of a slide valve fitted with the form of relief frame patented by Mr. W. Dawes in 1869.

The frame slides upon a planed surface on the inner side of the steam chest cover, and fits around the top of the slide valve. The connection between the frame and the valve is made by a plate of steel or bronze, about 0·05 in. thick, so arranged as to leave a considerable amount of elasticity while securing a steam tight joint between the valve and its frame.

Another form of relief frame may be seen on the engines of S.S. "Lopez" in the Marine Engineering Section. M.2511.

266. Models of balanced slide valve. (Scale 1 : 4.) Presented by Druitt Halpin, Esq., 1901.

In this arrangement, which was patented by Mr. James Smart in 1870, the valve is of the locomotive type, but has a small steam chest cast with it at each end. It works steam tight between V-shaped side guides, through a port in the upper part of which steam is admitted to the valve chests, while the lower one, which is also perforated, is connected with the drain cocks. One of these guides is made self-adjusting by springs, so as to keep the surfaces in contact, since owing to there being no surrounding steam chest, the only pressure keeping the valve to its face is that due to the action of the steam upon the difference between the internal back and front areas.

One model shows a cylinder fitted with this valve, while the other, together with a drawing, represents a pair of these valves in the chest of an inside cylinder locomotive in which, however, there would be no steam pressure. The arrangement was ultimately abandoned through the difficulty in maintaining the surfaces steam tight, owing to the distortion which took place when heated. M.2513.

267. Cylinder with drop-piston valves. (Scale 1 : 4.) Presented by Messrs. J. & W. McNaught, 1914.

This arrangement of steam engine valves, for reducing cylinder clearance to a minimum, was patented by Mr. W. McNaught in 1908.

There are four separate piston valves arranged at right angles to the axis of the cylinder and working in perforated liners fitted across the steam and exhaust passages, which are cast along the top and bottom of the cylinder. When the valves are moved outward they uncover the perforations and allow the steam to enter or leave the cylinder. The piston, which is made longer than usual, is allowed to approach as nearly as possible to the cylinder covers, and the valves have conical inner ends which project beyond the cylinder wall and are accommodated by notches formed in the piston and the cylinder covers. Holes are drilled through the valves to balance the steam pressure on their ends. The inlet valves are fitted with dashpots and are arranged to be operated by a trip gear; the exhaust valves may be worked by any ordinary gear. Inv. 1914—753.

268. Motion diagram of valve gear. Contributed by J. Seaward, Esq., 1860.

This shows in outline the cylinder, entablature, and standards of a vertical direct-acting paddle-wheel engine, probably of the "Gorgon" type. On one side the cylinder is shown fitted with a long D slide valve

worked, through a rocking shaft, by a single loose eccentric; on the other side is shown a short D slide valve, with relief frame on its back similarly driven.

It is probable that this model was made for comparing the action of the valves then in use with that of the type advocated by Mr. Seaward and shown in No. 269. M.334.

269. Motion diagram of Seaward's valve gear. (Scale 1 : 10.) Presented by Messrs. Bullivant & Co., 1902.

This shows a section of the cylinder, standards, and entablature of the engines fitted by Messrs. Seaward and Capel in 1837 in H.M.S. "Gorgon"; the general arrangement of these engines is shown by a model in the Marine Engineering Section, where the leading particulars are given.

The cylinder shows an early application of the system of separate steam and exhaust valves to each end of the cylinder, for the purpose of minimising clearance and exposed surface, in the way patented by Mr. Samuel Seaward in 1834; Watt and Murdock had previously adopted separate valves, but theirs were of the drop type. Each of the valves shown is a flat plate in a separate chest, the two steam valves being at the ends of one side of the cylinder and the two exhaust valves opposite them. The steam valves are hinged to their common valve rod, and are free to leave their faces, should water accumulate in the cylinder; the exhaust valves, however, work on faces formed on their chests. The four valves are worked by two adjustable bellcranks, rocked by a single eccentric on the crankshaft. Considerable economy in fuel was shown by engines fitted with this gear, and it was extensively adopted in H.M. Navy. M.1648.

270. Motion diagrams of Seaward's valve gear. (Scale 1:10.) Contributed by J. Seaward, Esq.

The first represents the arrangement adopted by Messrs. Seaward and Capel in their atmospheric engine, patented by Mr. Samuel Seaward in 1838.

Separate steam and exhaust valves, of the plate type introduced by Mr. Seaward, are employed, but the cylinder being open-topped, only two valves are required. These are worked by connected and adjustable bell-cranks driven by a single loose eccentric, which, however, is not shown in the model.

The second shows a modification of the arrangement of engine valves, patented by Mr. Seaward in 1834, and adopted by Messrs. Seaward and Capel in 1845, in the engines of H.M.S. "Avenger," a steam frigate of 650 h.p. It differs from that of the "Gorgon" class in having a cam on the crank-shaft, in place of an eccentric. The cam is stepped, so that different grades of expansion can be attained, and against it are pressed two rollers carried on bellcranks, by which the valves are moved; each roller, however, simultaneously actuates the steam valve at one end of the cylinder and the exhaust valve at the other. M.335–6.

271. Model of reversing gear. (Scale 1 : 10.) Woodcroft Bequest, 1903.

This is a model of the driving gear of an inside cylinder locomotive, fitted with a reversing arrangement patented by Messrs. A. Ogilvie and J. Richardson in 1858.

The slide valve of each cylinder is driven by a single eccentric, and the reversing is performed by a slide valve, moved by a lever from the footplate, and situated in the main steam pipe. Steam and exhaust pipes proceed from the valve chest of each cylinder, and by the hand-moved valve these steam and exhaust passages are interchanged.

This gear does not permit of expansive working, and is inferior to the link motion, but for certain purposes is more convenient, *e.g.*, some steam steering gears reverse in this manner. M.1836.

272. Model of valve gear. Presented by Thomas Silver, Esq., 1869.

This represents the form of slide valve and operating gear patented by Mr. Silver in 1864. The valve is elongated and has portions of its ends cut away so that the port area for steam admission is restricted, while the whole area is available for exhaust. Motion is given to the valve by a disc oscillated by an eccentric, the point of attachment of the valve rod being adjustable so that variable expansion and reversing are obtainable. Adjustment is effected by attaching the valve rod to the middle point of a link which slides upon two pins fixed in the face of the disc; a rack is formed on the back of the link and this gears with a pinion which is rotated by a worm and worm wheel. M.1185.

273. Original model of link motion reversing gear Lent by William Howe, Esq., 1893. Plate VI., No. 6.

This is the original wooden model made by William Howe, of the Forth Street Works, Newcastle, in 1842, to illustrate his invention of the link motion. It was submitted to Robert Stephenson, who at once tried it on a locomotive (No. 359) then being built for the North Midland Railway Co. (*see* No. 203). Since that time it has remained the most popular form of reversing gear owing to its simplicity and the ease with which it permits the point of cut-off of the steam to be varied, so reducing the consumption by allowing the steam to work expansively. It seems probable, however, that this device was originally designed to be a reversing gear only, its use in varying expansion not being discovered until later. The construction is described in connection with the larger model No. 275. M.2547.

274. Model of reversing link. Lent by William Howe, Esq., 1893.

This is a wooden model of a link and block designed by Howe in 1848, and fitted to a winding engine at Clay Cross in 1854; it is arranged so as to permit of adjustment for wear. The link consists of two bars connected at the ends, and carrying pins for the attachment of the eccentric rods. The block is in halves, each forming one half of the pin with flanges bearing on the edges of the bars. The valve rod has a strap end which holds the two halves in position, and permits of their being closed together when worn. M.2548.

275. Model of Howe's link motion applied to a locomotive. (Scale 1 : 2). Lent by T. Jeffrey, Esq., 1870.

This is a working model of what is usually known as Stephenson's link motion, as arranged for the reversing and expansion gear of locomotive engines; it shows a section through the cylinder, piston, slide valve, and ports, so that its effect upon the working of the valve can be observed. There are two eccentrics on the axle, one set in the correct angular position for going forward, and the other for going backward, and these are connected by rods, one to each end of a curved link, in which slides a block attached to the valve rod. The link can be raised or lowered by the reversing lever and thereby bring either end of it to act upon the valve rod, so that the valve receives motion from one eccentric or the other. By fixing the lever at intermediate positions, however, the valve is caused to receive a combined motion from the two eccentrics, equivalent to that from a single eccentric having a shorter travel and a greater advance, the effect of which is to cause an earlier cut-off in the cylinder. M.1829.

276. Model of Gooch's link motion (working). (Scale 1 : 4.) Made in the Museum, 1901.

This gear, known as the stationary link motion, was invented in 1843 by Mr. afterwards Sir Daniel Gooch, Bart., and employed by him on the Great Western Railway. The actual arrangement represented was that on a locomotive built in 1847, and the model shows a horizontal section through one of the cylinders, with its piston, slide valve, etc., together with the crank and eccentrics. With this gear, constant lead is secured for all degrees of cut-off owing to the link being curved to a radius equal to the length of the rod connecting the block with the end of the valve rod; this radius rod, however, makes the overall length of the gear greater than that with the shifting link. The link itself is suspended from a fixed point, and swings nearly horizontally, the point of attachment usually being at the centre of the link in engines that frequently run reversed. The eccentric rods are attached one to each end of the link, and the linking up is effected by altering the position of the block in the link by the usual reversing lever. M.3139.

277. Model of Allan's straight link motion. (Scale 1 : 2.) Presented by A. Allan, Esq., 1862.

This is a working model of the link motion, patented by Mr. Allan in 1855, for the valve gear of locomotives. One eccentric is set in the correct angular position for forward motion, and the other for backward motion of the engine. The reversing lever shifts both the link and the block at the same time, instead of shifting the link only, or the block only, as in former link motions. By this arrangement the link can be made straight: also the vertical height required by the gear is reduced. M.860.

278. Model of Walschaërts valve gear (working). (Scale 1 : 4.) Made in the Museum, 1901. Plate VI., No. 7.

In this valve gear the motion for the valve is derived from that of a point describing a circular path round the crankshaft combined with that from another point receiving a reduced reciprocating movement from the piston; the former component, which by a curved link can be varied and reversed, enables the grade of expansion to be altered or the engine to be reversed; the other component gives the lead, which is constant for all grades, the distribution being, therefore, rather better than that obtained with link motions.

The original form of this gear was introduced in 1844 by Mons. E. Walschaërts, of the Belgian State Railways, but it had an unnecessarily complicated arrangement of the link; he had corrected this before 1848 and so brought the gear to its present form except that he still used one eccentric.

Although from its introduction this gear was occasionally used and was generally known to give an excellent steam distribution, it made but little progress till after 1859, when, on some outside cylinder Crampton engines, built for the Northern Railway of France and fitted with it, the single eccentric hitherto retained was displaced by a light return crank, as shown in the model, thus avoiding the use of eccentrics. As thus simplified, the motion has been generally adopted in Belgium since 1860, and in Germany since 1875; nearly all modern Continental locomotives now have their valves actuated in this manner.

The model shows the gear as arranged on an engine, built about 1883 for a French railway; the cylinders are 17·3 in. diam. by 25·6 in. stroke and drive four coupled wheels 79·5 in. diam. The slide valves are of the piston type, placed above the cylinders, which, as in most Continental locomotives, are outside the frames. Each valve is driven by a lever, the bottom end of which is connected with the crosshead and an intermediate point close to the top end with the valve spindle. The top end is connected with a radius rod, whose other end fits in a curved link, within which its position is

adjustable by the reversing lever. This link is rocked by a pin on a return crank from the main crank pin and 90 deg. behind it. By this arrangement the motion of the valve spindle is compounded of two motions, one derived from the crosshead, giving the lead, and the other from the link rocked by the eccentric pin, giving a motion corresponding to that from an eccentric 90 deg. in advance of the crank pin; but this motion is capable of reduction and reversal by moving the end of the radius rod in the rocking link. The details of the gear represented are:—travel, 5·05 in.; outside lap 1·18 in.; lead, 0·2 in.; and maximum opening to steam, 1·34 in.

This valve motion is shown on the Fairlie locomotive (*see* No. 230), on the four-cylinder compound locomotive (*see* No. 247), and also on the compound marine engines of the P.S. "Princesse Henriette" (*see* Marine Engineering Section).

An interesting modification of this gear was devised in 1868 by Prof A. Stévart for application to an engine with two cylinders placed either in planes at right angles working the same crank, or in the same plane on cranks at right angles; from the crosshead of one cylinder is obtained that part of the motion for the valve of the other usually derived from an eccentric, the complete motion for the two valves being thus obtained entirely from the two crossheads. Successful modifications have also been introduced by Messrs. Kitson, of Leeds, and other engineers. M.3175.

279. Motion diagram of Joy's radial valve gear (working). Presented by David Joy, Esq., 1900.

This gear, which was patented in 1879–80 by Mr. Joy, is both a reversing and a variable expansion gear, but no eccentrics are used, the motion of the valve being derived from the swing of the engine connecting rod.

The valve rod is attached to the short end of a long lever, the other end of which is indirectly coupled to the engine connecting rod. The fulcrum of this lever is fitted with a block sliding in a curved guide, and the engine is reversed or "linked-up" by altering the angle that this guide makes with the valve rod. The guide is shaped to a circular arc of a radius equal to the length of the valve rod, and the block, when the engine is running, works equally on both sides of the centre of this guide. As the crankshaft rotates, any point on the connecting rod has a nearly elliptical path, which would give an unequal distribution of the steam at the two ends of the cylinder if the long lever were directly attached to the connecting rod. To avoid this objection the motion is obtained from a link, one end of which is attached to the connecting rod and the other to a radius rod. A point in this link describes an oval path, which gives a symmetrical motion to the slide valve.

It is stated that, in mid-gear, steam is admitted into the cylinder to the extent of the lead at each end, and that the lead is constant for all positions, while unequal lead can be arranged for, if preferred. A valuable feature of this gear is that it readily brings the valve chest into a position at right angles to that usually occupied.

For the sliding block and a curved guide, a swinging lever is sometimes substituted, the inclination of the curved path so obtained being altered by changing the position of the stationary end of the lever. Photographs of several varieties of engines so fitted will be found in the collection.

M.2658.

280. Model of Morton's valve gear (working). (Scale 1 : 4.) Lent by Morton's Valve Gear Patents Co., 1889.

This radial valve gear without eccentrics was patented in 1882 by Mr. A. Morton; it is shown fitted to a vertical marine engine.

A radius rod, nearly in a line with the valve rod, controls the free end of a lever, which receives a compound motion from the connecting rod and the crosshead. From a point in this lever a rod extends to a pin in a curved slot

rigidly attached to the slide valve; the position of the pin in this slot determines whether the engine is in forward or backward gear, and also the grade of expansion. The rod from which the valve is directly operated describes a nearly elliptical path, with the major axis horizontal, and so gives a very uniform steam distribution at both ends of the cylinder.

M.2670.

281. Model of valve gear. (Scale 1 : 4.) Presented by Harry Gray, Esq., 1897.

This gear, patented by Mr. Gray in 1893, combines the link of the common reversing motion with the single eccentric of Hackworth's gear; it is stated to give great latitude in adjusting the various points of cut-off.

The eccentric is set opposite the crank, and has two straps and eccentric rods corresponding with forward and backward gear. These rods sway rocking levers to which the rods from the two ends of the link are attached. Although the link is a shifting one, it is found that the least variation in lead is obtained with the reversing link curved convex to the shaft. M.2989.

282. Motion diagram of Joy's fluid-pressure reversing gear. Presented by David Joy, Esq., 1900.

This shows the arrangement of valve gear, patented by Mr. Joy in 1892, for altering the point of cut-off of an engine, or reversing it, by moving the eccentric sheave in a straight line from the position for forward gear to that for backward.

The eccentric is forced over by means of fluid pressure, acting upon rams formed on the crankshaft and working in cylinders fixed within the eccentric sheave. The fluid is introduced to these cylinders through central holes drilled along the crankshaft, and by pipes connected with the fluid distributing arrangement. This consists of two vertical cylinders with a common piston rod, the upper cylinder being for steam, and the lower for oil or other fluid that is under pressure. Steam is admitted to either end of the upper cylinder through a small slide valve worked by the hand lever, and there is also a slide valve in the oil cylinder. The steam admitted into the upper cylinder moves the piston in the oil cylinder, and so, by the fluid connection, moves the eccentric over to a corresponding extent. If the oil leaks or an eccentric ram leather gives way, the eccentric goes to full gear, forward or backward, according to the way the engine is running, and remains there.

An adjacent photograph shows this gear as fitted to a locomotive, but with the parts opened out so as to render the construction visible. M.2658.

283. Slide valve. Presented by D. Halpin, Esq., 1909.

This is an example of the slide valve for variable expansion, patented by Mr. Halpin in 1882.

The valve is formed with a cylindrical bearing surface and slides on a similar valve face. The central exhaust port has its edges at right angles to the axis, while the steam ports are triangular, having their outer edges inclined to it. The valve is of corresponding shape, and, besides being reciprocated longitudinally by one eccentric, it receives a rocking motion in its seat from another eccentric, by means of an external lever attached to the valve spindle which is provided with a swivel joint. Varying the amplitude of the rocking motion, which may be performed by the governor, alters the cut-off without affecting the lead or exhaust. The steam ports and the edges of the valve are formed in two parts, so as to reduce the angular motion required.

M.3634.

284. Photograph of engine with Corliss valve gear. Lent by Messrs. Hick, Hargreaves & Co., 1888.

The engine represented is fitted with a modification, patented by Mr. W. Inglis in 1863, of the Corliss valve gear originally brought out in 1848. The valves are operated by "wrist plates" rocked by eccentrics on a countershaft connected with the crankshaft, but the closing of the steam valves is effected, when released or tripped, by helical springs in small air dash-pots. The period of reease is determined by a high-speed governor, assisted by a supplementary one patented by Mr. W. Knowles in 1883, its function being to vary the length of the rod from the main governor to the trip gear, and so remove the slight change of speed that had caused the main governor to alter its height.

The engine is of the tandem two-stage expansion type, with cylinders 32 and 54 in. diam. by 6 ft. stroke; under steam at 85 lb. pressure, it makes 51 rev. per min. and indicates 1,200 h.p. M.1898

285. Model of automatic expansion gear. Presented by D. Halpin, Esq., 1901.

In this valve motion by Mr. Halpin, there is a single slide valve and two eccentrics; one eccentric gives a simple reciprocating motion that controls the exhaust, while the other rocks a bellcrank lever, which rocks another bellcrank lever connected with the slide valve in such a way that it gives a vibrating motion to the valve. The outer lips of the valve have a curved outline, so that any alteration in the angular position alters the lap; to make the arrangement more compact, the curve is made in two portions. The point of cut-off is altered by moving the position of a link in a slot of the bellcrank lever, and this can be done automatically by a governor. M.2513.

286. Diagram model of automatic expansion gear (working). Lent by Messrs. T. McCulloch & Sons, 1887.

In this gear, designed by Dr. W. R. Proell, and patented in 1881, a double beat valve is used as an expansion valve. The opening is caused by an eccentric, through the medium of a rocking lever and bellcrank; the closing, when released, is done by a spring. The releasing is performed by a trip motion, the time of which is controlled by the position of the governor. In the model there are two bellcranks, mounted on a rocking lever which is oscillated by an eccentric. The vertical arms of the bellcranks alternately, in their downward motion, lift the valve; the horizontal arms, by which the tripping is effected, are under the control of the governor. M.1858.

287. Motion diagram of automatic expansion gear. Made by Messrs. H. & T. C. Batchelor, 1889.

This valve gear, patented in 1882 and 1884, by Mr. C. J. Galloway and Mr. J. H. Beckwith, is intended for use in an engine having an independent exhaust valve and two steam valves driven by separate eccentrics. The diagram shows the eccentric and gear for one of the steam valves. The slide valve rod is moved a certain distance by the eccentric until a catch liberates the valve rod, when it shoots back to the closed position under the action of a spring or piston, a dash-pot being added to stop the valve quietly after the port has been covered.

The proportion of the piston stroke that is performed before the catch is liberated is determined by the engine governor. The motion from the eccentric is transmitted to the valve rod by a short horizontal lever, which, when slightly lowered, catches a projection on the valve rod. The lever has a roller connected with it rolling on a fixed incline, the amount that the roller is below the lever being determined by the speed of the governor, so that the distance rolled up the incline before the lever is lifted high enough to release the valve rod and so cut off the steam, is automatically controlled.

A photograph of an engine so fitted is also shown. M.2271.

288. Motion diagram of the Willans central-valve engine (working). (Scale 1 : 2.) Made by Messrs. H. & T. C. Batchelor, 1889. (*See also* No. 131).

The engine has three vertical steam cylinders of increasing diameters placed tandem; the common piston rod is hollow and of large diameter, and inside this rod travels the slide valve by which the steam is directed through the various cylinders. Each cylinder is single-acting only, the space between each piston and the top of the cylinder below forming a receiver. As the valve face travels with the piston the single eccentric which moves the slide valve is secured to the crankpin, thereby giving the same relative motion as is usual with a fixed valve face. Immediately above the crankshaft is a fourth cylinder, which forms a guide for the crosshead, which, in this case, is a long piston. This piston in the up-stroke compresses the air confined in its cylinder, and so maintains sufficient thrust on the connecting rods, etc., to prevent any knocking through the rapid reversals of the motion of the pistons, etc. Owing to the unbalanced end pressure on the long piston valve the stress in the eccentric rod is never reversed. The crank and connecting rods are lubricated at every revolution by their dipping into a bath of oil, contained in the lower portion of the crank chamber. High pressure steam is let into the upper dome or steam chest from which it passes by radial holes into the hollow piston rod, down and out into the high pressure cylinder. When the piston has descended some distance its supply of steam is cut off, owing to the upper ports through the rod becoming covered by the packing round it at the upper end of the cylinder. This steam expands till the down stroke is completed, and then, during the up-stroke, exhausts from the top of the first cylinder into the lower end, which forms a portion of the first receiver. In the second revolution this steam similarly passes through the second cylinder, and, after the third revolution, will have reached the lower side of the low pressure piston, where it is discharged into the atmosphere or into a condenser. M.2273.

289. Motion diagram of automatic expansion gear. Made by Messrs. H. & T. C. Batchelor, 1889.

In this valve gear, patented in 1885 by Mr. J. Wheelock, the cylinder has separate steam and exhaust valves at both ends, all in the form of wide grid-iron slides. The seats for these are formed on skeleton plugs secured into long, slightly conical holes, which are bored transversely to the cylinder. At the back of each slide is a short crank arm connected with the slide by a link, and these cranks are rocked from a single eccentric on the engine shaft. The steam admission valves each have their crank rocked by a latch lever connected with the external mechanism of the exhaust valve, but when the lever is lifted the valve is closed suddenly by a spring or weight checked by a dash-pot. The instant when the latch lever disengages is automatically determined by a cam lever controlled by the engine governor, so that any increase in the speed will cause the cut-off to take place earlier in the stroke. The introduction of the short cranks at the backs of the slides causes the exhaust valves to remain fully open for a longer time than would otherwise be the case, while with the steam valves considerable variation in the action of the dash-pots is possible without its causing any imperfect closing of the steam ports.

In recent engines double grid valves and seats are adopted for high pressures. M.2276.

290. Sectional model of automatic expansion gear. (Scale 1 : 4.) Lent by Messrs. Holborow & Co., 1886.

This represents a horizontal engine fitted with the valve gear patented in 1885 by Mr. H. G. Holborow.

In the steam chest is a main slide valve, worked by a single eccentric, and on its back is a gridiron cut-off plate worked by another eccentric; the motion of this cut-off valve is controlled by a Porter governor in such a way that the proportion of the stroke done under full steam is decreased upon there being any increase in the speed of the engine. The expansion eccentric rocks a link, one end of which is carried by a pin moving with the main valve, and the cut-off valve rod has also a slotted link; into these two slots passes a block connected with the governor, which, by altering the position of the block, determines the amount of relative motion which the back plate receives from its eccentric and thus determines the point of cut-off; the opening and closing of the exhaust port, being done by the main slide valve, remain unaltered. K.486.

291. Motion diagram of locomotive valve gear with "Corliss" valves. (Scale 1 : 5.) Constructed by Mons. P. Regnard, 1899.

This shows a valve gear patented in 1890 by MM. Durant and Lencauchez, and considerably used on the Paris and Orleans Railway for both express and goods engines.

Each of the cylinders has two semi-rotating steam valves at the top, and two similar exhaust valves below. Such cylinders have been fitted to existing engines, the original valve motions, which were of the Gooch type, being retained. The two steam valves are worked by a rod from the block in the usual way, while the exhaust valves are driven from another point in the block through an intermediate lever; linking up and reversal are performed by moving the block in the ordinary manner.

The large port areas, reduced clearance, and diminished "wall" surface secured by this arrangement were stated in 1893 to have shown a reduction of 15 per cent. in the steam consumption, when compared with that of similar engines with ordinary slide valves, and that the wear of the valve gear was still more materially reduced. M.3043.

292. Motion diagram of Holt's reversing gear. Lent by H. P. Holt, Esq., 1879.

This auxiliary steam reversing gear was patented by Mr. Holt in 1876. The reversing piston has its motion controlled by a three-ported slide valve connected with the reversing lever, but also receiving motion from this piston. The ports of this valve are always open to the cylinder, but the passage of steam is prevented by a back cut-off valve of the ordinary type, without any lap. For each position of the control valve, which is moved by a hand lever, there is a corresponding neutral position for the three-ported valve, and therefore of the piston and reversing lever, so that any motion of the small valve is followed by a corresponding movement of the reversing piston until steam is again cut off from both ends of the cylinder. M.2512.

293. Joy's assistant cylinders for slide valves. Presented by David Joy, Esq., 1897 and 1900.

These two examples, one of which has been sectioned, were fitted in 1889 to the engines of H.M. torpedo-boat destroyer "Speedwell"; they remained in use till 1900, and were then replaced by a later modification of the design.

The assistant cylinder was patented by Mr. Joy in 1886–7 for reducing the wear and frictional losses on the valve mechanism of large slide valves by directly applying steam power to perform the greater portion of the work. It is placed above the steam chest, in the position usually occupied by the balance cylinder in vertical engines, and is provided with a piston attached to the rod of the main slide valve. On the side of the assistant cylinder is a small slide valve of the piston type, which distributes high pressure steam to the two ends of the assistant cylinder; this valve is moved by steam acting on one of its

ends and admitted from the assistant cylinder when its piston, on approaching either extremity of its travel, exposes a small port communicating with one end of the valve. The travel, and consequent port opening, of the piston valve is controlled by adjustable end stops, while the ports of the assistant cylinder are connected by a plug valve, which forms a by-pass should it be required to put this cylinder out of action.

By the action of this arrangement the momentum of the moving valve when nearing the end of its travel is at first absorbed by cushioning, assisted finally, by live steam admitted through the piston slide valve; this steam then does the work of reversing and restarting the valve, the ordinary valve gear merely controlling the motion.

The adjacent sectional drawing shows a later and simplified form of the invention. In it the engine valve rod is provided with an elongated piston containing two side ports, which alternately coincide with a central port in the assistant cylinder when this piston is at either end of its travel; the piston in these positions also uncovers one of the two exhaust ports. If the valve in the diagram is imagined to be moving upward, the motion will at first close the upper exhaust port and compress the steam at the top of the cylinder, while, when nearly at the top of its stroke, boiler steam will be admitted from the steam belt through the ports in the piston to the upper end of the cylinder; this charge of steam finally checks the motion of the valve and afterwards assists the downward travel until the upper exhaust port is again opened, and so on. The work is done chiefly by cushioning, so that the actual consumption of steam by the cylinder is small, while, by adjustments, the downward tendency due to the weight of the valve is corrected. This diagram shows also copies of indicator cards, taken from the two ends of the cylinder, which explains the small steam consumption involved. M.3010.

Governors.

294. Model of cataract governor. Received 1883.

This shows the hydraulic governor used for "tripping" the valve gear of a Cornish pumping engine, and by which the number of strokes per minute can be adjusted to the work to be done, owing to the alteration it permits in the interval of rest at the completion of each double stroke. In many engines, however, there are two cataract governors, so that there is a period of rest at the end of each stroke during which the pump valves return to their seats.

The arrangement consists of a weighted plunger in a vertical cylinder arranged in a water cistern, from which, when the plunger is raised, water enters the cylinder through a non-return valve; upon the plunger being released it descends at a rate determined by the amount by which a valve at the side of the cylinder is opened. The plunger is raised by a lever moved by a tappet on the plug rod of the engine valve gear, and the subsequent descent of the plunger lifts the catches, and so releases the valve that controls the next stroke of the engine. A complete cataract valve gear is shown in action on the Cornish pumping engine No. 615. K.363.

295. Experimental chronometric governor. Presented by John Hick, Esq., 1887.

This is a very simple form of governor, patented by Mr. Benjamin Hick in 1840, for controlling the throttle valve of a steam engine, and depending for its operation upon the resistance offered by the air to the rotation of a fan. The boss of the fan is a nut working on a quick-threaded screw cut on a vertical spindle driven by the engine. The resistance of the air retards the fan, and its nut mounts the thread of the screw when the speed of the spindle increases. This motion partly closes the throttle valve. M.1839.

296. Steam engine governor. Contributed by Sir C. W. Siemens, 1860.

In this governor, patented in 1844–5 by Mr. J. Woods and Sir C. W. Siemens, the top horizontal bevel wheel is driven by the engine, and drives the horizontal bevel wheel below it (which is carried by a hollow vertical shaft), through the medium of the two intermediate vertical bevel wheels. Hung from the hollow vertical shaft are two semicircular weights, which revolve freely within the casing up to a certain speed, and beyond that speed fly out and rub against the casing. The extra power required to be transmitted through the intermediate wheels to overcome the friction causes them to be carried bodily a few degrees round about the vertical shaft; the weighted lever, which opposes their motion, being lifted, and acting upon the throttle valve regulates the steam. Inv. 1858–58.

297. Model of engine governor. (Scale 1 : 8.) Presented by T. Silver, Esq., 1869.

This form of throttle valve governor was patented by Mr. Silver in 1855–7. It has crossed arms with balls on the end of each, the action of gravity being thereby neutralised, so that the governor can be used in any position or at sea. When the balls fly outward under centrifugal action, they are resisted by a spring connected with the sleeve working the throttle valve. M.1183.

298. Chronometric governor. Lent by J. Standfield, Esq., 1863.

This governor, patented in 1861 by Mr. J. Standfield, involves the same principle of intermediate bevel wheels as does that of Siemens, No. 296; and will be more readily understood by reference to the latter; in this case, however, there is also a dial for indicating varying speeds, and the resistance against the carrying round of the intermediate bevel wheels and the consequent shutting of the throttle valve, is provided by an adjustable coiled spring.

The resistance to the rotation of the governor is provided by a dash-pot or revolving vessel containing water. This vessel is provided with internal vanes, which carry the water round, and dash it against other vanes, within the vessel but mounted on a vertical spindle, which is prevented from rotating by a spring balance with index and dial. When the speed is increased, the work done in agitating the water is increased, and the pressure exerted by it against the shaft vanes turns the vertical shaft through a portion of the revolution, at the same time indicating the speed on a scale on the dial. M.1771.

299. High-speed governor. Lent by Messrs. Ormerod, Grierson & Co., 1887.

This is a form of high speed steam engine governor, designed by Mr. C. T. Porter about 1858, and used very largely for stationary engines.

The governor has a pair of arms pivoted at the top of a rotating spindle, and carrying small balls at their lower ends; two links connect the balls with a sliding sleeve, and this is loaded with a large central weight which tends to pull down the balls without increasing their centrifugal action. The sleeve is connected with the throttle valve by levers and rods. This, and other forms of governors running at high speeds, can be made as sensitive as desired, and are more powerful than the older forms having large balls running at low speeds, examples of which can be found on the beam engines of James Watt (*see* Nos. 67 and 69). M.1870.

300. Spherical governor. Presented by Messrs. John Bourne & Co., 1872.

This construction of governor was patented in 1870 by Mr. John Bourne. It consists of a thin hollow brass spheroid divided by axial cuts into a number of flexible bars or ribbons. When rotated at a high speed, the centrifugal action causes the spheroid to increase in transverse diameter and diminish in length. This change gives motion to a collar which is connected with the throttle valve; there is an axial screw fitted with a wing nut by which the action of the governor can be varied. M.1261.

301. Buss governor. Lent by Messrs. Schäffer and Budenberg, 1888.

In this regulator, patented by Messrs. E. and W. Buss in 1870, a hollow vertical spindle, driven from the engine, carries at its upper end a bracket having four arms directed downward. These serve as centres for two swinging frames, each consisting of a horizontal portion, forming an axis, with two arms carrying weights at right angles to one another, the weight on the vertical arm being much smaller than that on the horizontal one, which is on the opposite side of the vertical axis. The frames are directly connected with a crosshead on a sleeve capable of sliding on the spindle and carrying with it an internal rod, which is connected with a throttle valve, arranged below, and controlling the supply of steam to the engine. This construction gives a governor which is in neutral equilibrium at its extreme positions 20 deg. apart, while between these extremes it is very sensitive but possesses sufficient stability for the purpose of steam engine regulation. M.1954.

302. Steam-engine governor. Presented by W. D. Scott-Moncrieff, Esq., 1911.

This is an example of the form of governor patented by Mr. Scott-Moncrieff in 1872. In it a centrifugal pump forces oil into a cylinder containing a loaded piston; an increase of speed increases the oil pressure, so raising the piston and partially closing a throttle valve with which it is connected.

The governor has a cylindrical chamber with a central diaphragm, one half forming an oil reservoir and the other the pump chamber. The oil enters the pump at the centre from the reservoir, and passes into a vertical cylinder cast on one side of the chamber. The piston is an easy fit in the cylinder, so that a small quantity of oil leaks past it, and is returned to the reservoir. The piston rod passes through a stuffing box, and is connected with the weighted arm of a pivoted lever, the opposite arm of which is attached to the spindle of a rotating throttle valve. The speed is regulated by varying the position of the weight on the lever. The pump spindle runs in bearings in the chamber ends, and one end passes through a stuffing box, and has the driving pulley fixed to it. M.3970.

303. High-speed governor. Lent by Messrs. Schäffer and Budenberg, 1888.

This is a steam engine governor of the form patented by Mr. E. Buss in 1876. The mechanism is mounted on a fixed vertical spindle projecting from a casing containing a cylindrical throttle valve. A long gunmetal sleeve fits over this spindle, which is suspended by a steel screw at the top and rotated by bevel gearing at the lower end; near the top of the sleeve lugs are formed, and below these a collar. A hollow spherical casing surrounds the sleeve and rotates with it, but is free to slide vertically; this has formed within it supports for the axes of four double-armed pendulums, the longer vertical arms of which project through the casing and carry balls at their lower ends, while the shorter horizontal arms turn towards the spindle and are connected with the sleeve lugs by short links. A helical spring is placed between the sleeve collar and the bottom of the casing. A rod is connected at one end with the lower part of the casing and at its lower end to a crank fixed on the

valve spindle. When the engine shaft rotates above the normal speed, the balls fly outward and they, together with the casing, move upward compressing the spring; this movement acts upon the valve and so reduces the supply of steam. This form of governor can be made as sensitive as desired, and, while being compact, has a considerable motion between its extreme positions; the whole of its working parts, except the sleeve, are utilised in producing the controlling force. M.1954A.

304. Automatic expansion regulator. Lent by Messrs. Wilson Hartnell & Co., Ltd., 1911.

This is an example of the form of steam engine governor patented by Mr. W. Hartnell in 1876. It is very powerful, as the controlling force is derived mainly from a compressed spring, the initial compression of which can be adjusted so as to make the governor as sensitive as desired. It was originally designed for use with expansion gears which automatically control the point of cut-off of the steam in the cylinder, but is now used for all types of engines with throttle valve control.

The governor consists of a cylindrical casing keyed to the shaft, having at its lower end projecting arms which support the pivots of the two bell-crank levers. The vertical arms of the bellcranks carry the governor balls, while the horizontal arms carry rollers bearing upon the upper flange of a sliding sleeve which surrounds the shaft and is pressed downward by a helical spring contained in the casing; the lower end of the sleeve carries a fork collar with which the expansion gear is connected. The governor is made as frictionless as possible by the use of ball bearings for the bell-crank pivots, and ball thrust bearings at top and bottom of the sleeve. Cork buffers are provided for the balls to rest upon when at their minimum radius. When working, the balls move nearly horizontally so that gravity has little effect; the vertical compression of the spring is equal to the radial motion of the balls, which makes the governor very sensitive, so that it will move from its full load position to no load with little change of speed. The sensitiveness is usually 2·5 per cent. from the mean speed for ordinary governing, and 1·25 per cent. for electric lighting. These governors are also made with an external spring by means of which the speed can be varied while running.

The example shown is designed for a mean speed of 280 rev. per min., and has a power of 100 ft. lb., with a sleeve rise of 3 in. It is suitable for the link expansion gear of an engine having a cylinder about 14 in. diam. M.3919.

305. Engine governor. Lent by Messrs. Napier Bros., 1888.

This, which is known as the "cat" governor, works on the principle of Froude's dynamometer. It was patented in 1880 by Messrs. J. D. and R. D. Napier.

A wheel, shaped like a saucer, with internal curved paddles or vanes, revolves rapidly in a tank of water. A similar wheel, mounted on another spindle, faces the first. The vanes of the revolving wheel dash the water with more or less violence, according to the speed against those of the second wheel, giving the latter a tendency to rotate, and close the throttle valve; this tendency is resisted by a lever, weighted according to the speed required. A duplicate pair of wheels is placed beside the apparatus to show the construction. M.2260.

306. Allen's governor. Lent by Messrs. Whitley Partners, 1892.

By this governor the supply of steam is regulated by the frictional resistance of a paddle immersed in fluid, and driven by the engine.

It consists of a standard carrying a shaft, which is driven by a pulley and has a six-armed paddle-wheel keyed to it. The wheel is enclosed in a casing attached to a shaft on the same centre line as the driven shaft. The interior

of the casing is provided with ribs, which just clear the paddles, and is partly filled with oil, so that by the rotation of the paddles the fluid exerts a considerable force, tending to rotate the casing by a kind of fluid coupling. The motion of the casing is, however, resisted by an adjustable weight hung by a chain from a suitable cam on its shaft, so that the action of the weight increases as the casing is carried round. On the shaft of the casing is a pinion gearing into a segment on the lever of the throttle valve, which is of the equilibrium piston type and contained in the base of the governor. A sectional drawing is also shown. M.2469.

307. Pickering's governor. Lent by Messrs. Joseph Evans and Sons, 1891.

Three balls are employed, each fixed in the middle of a separate plate spring. The lower ends of these springs are attached to a collar formed on the driving pinion, which runs free on a fixed central tubular column. The upper ends of the springs are secured to a cap at the top of the column, the cap being free to revolve and to rise and fall, so that as the balls diverge under the centrifugal force the top cap is drawn down, carrying with it a central shaft which is connected with a throttle valve contained in the lower casting. A helical spring is arranged to act upon an arm connected with the central spindle, and by means of a worm and worm wheel can be adjusted so as to alter the speed while running. The example shown is for a steam pipe 1 in. diam., and should make 300 rev. per min. M.2392.

308. Porte-Manville electrically controlled regulator. Lent by Messrs. Woodhouse & Rawson, 1887.

This piece of mechanism for controlling electrically the speed of engines or other motors was patented in 1884 by Messrs. A. E. Porte and E. Manville.

On a horizontal spindle are two ratchet wheels of equal diameter, but with their teeth cut oppositely. These wheels are secured to a bevel wheel on the same axis, gearing with a bevel wheel on a vertical shaft, which is connected with the steam throttle valve, a set of resistances, or other means for controlling the energy supplied to the motor. On the horizontal spindle is also a rocking frame carrying two opposite pawls which by springs are lifted clear of the ratchet wheels, but the frame is provided with two electro-magnets, each powerful enough when excited to pull the pawl above it into gear. The rocking frame is connected by an arm with some reciprocating part of the motor, so that when a pawl engages, the power brought upon the controlling gear may be very great if required. The actual regulation is determined by the apparatus that sends the current through one or other of the two coils as necessary, the appliance shown being a means for enforcing these corrections. To prevent over-winding, a block on the vertical shaft screws up and down, and breaks the circuit when in the extreme positions. M.2219.

309. Lindley's steam engine governor. Lent by Messrs. Browett, Lindley & Co., 1890.

In this governor, patented by Mr. H. Lindley in 1884, the usual balls are replaced by two hemispheres capable of swinging outward round two lower centres, but forming, when closed, one sphere. The centrifugal tendency of the two hemispheres is resisted by two helical springs acting directly while the spreading motion of the revolving masses is transmitted by upper links to a central spindle which passes downward to an equilibrium throttle valve placed in the steam pipe below. By means of a sliding block, which can be adjusted while the governor is running, the action of a third spring can be caused to increase or diminish the resistance to centrifugal force, thereby altering the speed of the engine. M.2291.

310. Expansion governor. Made by Messrs. Schäffer and Budenberg, 1894.

This governor regulates the speed by cutting off the steam at an earlier point in the stroke when the speed rises above the normal amount, so giving a higher grade of expansion as the power required from the engine diminishes. It is arranged for fitting to a simple engine with the ordinary slide valve, and so converts it into one with an automatic expansion gear.

The upper part consists of a Buss governor similar to No. 301, but below this, instead of a throttle valve, is a cylindrical gridiron valve. This valve is in the main steam pipe, as near the cylinder as possible, and is slightly oscillated by a trip gear rocked by the eccentric rod of the ordinary slide valve. The gear consists of a horizontal rocking shaft carrying two catches, which engage with a stop on the expansion valve spindle, but when free the valve is returned by springs to the closed position. The catches project upward as curved horns, while a nearly horizontal arm from the governor spindle obstructs the swing of these horns, and so releases the catches at a period of their swing dependent upon the position of the governor balls. A dash-pot is provided to steady the tripping arm. M.2563.

311. Enclosed spring governor. Lent by Messrs. Wilson Hartnell & Co., Ltd., 1911.

This example of a high speed governor, constructed on the same principle as the Hartnell expansion regulator (*see* No. 304), is designed for a colliery over-winding gear. It has four balls or weights placed symmetrically round the spindle, and the whole mechanism is enclosed in a cast iron or steel casing.

A pair of large weights lift the sleeve 0·5 in. at 200 rev. per min., when their movement is arrested by the enclosing casing. There is also a pair of very small weights which lift the sleeve another 0·5 in. at 2,000 rev. per min.

Similar governors, with one or two pairs of weights, running at speeds from 500 to 2,000 rev. per min., are used for regulating water or steam turbines, etc. M.3937.

312. Hartung's governor. Presented by Messrs. Hartung, Kuhn & Co., 1905.

This governor, which was patented by Herr H. Hartung in Germany in 1893, and is widely used, is of the spring-loaded centrifugal type.

The weights are flat but shaped on the rim to suit an external cylindrical casing keyed to the vertical governor spindle. Each weight is supported on the double arm of a bellcrank lever which has its fulcrum in the casing, whilst the other arm is attached by a link to the sliding collar. The weights in all positions thus deviate but slightly from one horizontal plane so that the disturbing effect of gravity is almost eliminated. The weights are loaded by helical springs placed in recesses bored in them and bearing against plugs screwed on a through bolt, thus allowing of adjustment within narrow limits. This linkwork therefore remains unloaded; internal friction is consequently small, which makes the governor sensitive and reduces wear. The governor is so nearly isochronous, that a wide range in the number of revolutions cannot be obtained by altering the tension of the springs. Weights, however, may be placed on the sliding collar or a spring balance may be attached to the linkwork for this purpose; this, however, increases friction and diminishes sensitiveness. The casing acts as a protection against dirt, etc., while the top is easily removable to gain access to the springs. M.3386.

313. Shaft governor. Lent by A. S. F. Robinson, Esq., 1904.

In this arrangement of centrifugal governor directly secured to the engine shaft, the speed of the engine is regulated by its varying the point of cut-off

to suit the load. It accomplishes this by altering the position of the eccentric on the shaft in such a way that the angular advance and travel of the valve are varied while the lead remains constant. It was patented in 1894–9 by Mr. Robinson.

The mechanism is enclosed in a hollow flywheel or pulley fixed to the engine shaft, while the eccentric sheave is carried on one side of a frame composed of a pair of guide plates, placed one on each side of the wheel and connected by four shouldered studs passing through slotted holes in the wheel faces. The studs are joined in pairs by two bridge pieces, which are each tied by two steel strips to opposite lugs on the inside of the wheel rim. The eccentric frame and strips form a "Watt" parallel motion, constraining the eccentric to move approximately in a straight line at right angles to the crank, so as to maintain a practically constant lead. This frame is held in position by a pair of laminated steel springs, curved outward round the boss and passing between the parallel motion strips; these springs are fixed at one end to adjustable supports attached to the wheel and at the other to one of the bridge pieces of the sliding frame. The springs are controlled by four swinging levers pivoted at the flywheel rim and coupled together in pairs by links and compensating levers; these act through links and rolling contact pieces which bear upon the inside of the curved part of the springs, so that when the levers fly outward the springs are pulled apart and the eccentric frame is moved towards the centre.

The speed of the engine is adjusted by moving the fixed ends of the laminated springs, which can be effected while the engine is in motion by means of a disc sliding along the shaft; this disc carries a projecting rack, which engages with a pinion attached to a right and left handed screw passing through the ends of short levers upon which the springs are mounted.

M.3341.

314. Jahns governor. Lent by Messrs. Boving & Co., Ltd., 1913.

This is an example of the centrifugal governor, for high speed engines and steam turbines, patented by Mr. W. Jahns in 1912. It is very sensitive, as the weights move horizontally, and is constructed so as to eliminate friction as far as possible.

The governor is contained in an oil-tight casing fixed to the top of a vertical shaft. The weights are flat and are fitted with vertical and horizontal rollers running on planes prepared for them on the casing. The weights are pressed towards the centre by helical springs, fitting into recesses in them, and tightened up by nuts screwed on a central stud passing through a hole in the top of the shaft. The nuts fit into holes in the cylindrical portion of the casing, and the springs are adjusted by inserting washers behind them. Vertical slots, formed through the weights, engage with rollers mounted on the upright arms of two bellcrank levers pivoted on the casing; the lower arms of these levers engage with inclined slots formed on a sliding sleeve inside the casing, and this sleeve is connected with another, outside the casing, by two rods passing through holes. Arrangements are provided for leading oil from a central reservoir to the upper bellcrank rollers, while the weight rollers are always immersed in oil. Inv. 1913–25.

Lubricators.

315. Suet lubricator. Lent by Messrs. Nettlefolds, Ltd., 1888.

This is a cup lubricator, designed for using suet or other grease which requires heat to liquefy it, as sometimes supplied to steam cylinders or large bearings; it was patented in 1866 by Mr. J. Storer. The cover for filling is secured by a bayonet joint, made steam tight by having a sharp edge, which

is forced down on a soft metal seating by an external screw. Internally there is a cylindrical strainer to keep back solid matter and prevent choking of the outlet pipe. The rate of feed is regulated by a cock. M.1944.

316. Grease lubricator. Lent by Messrs. Trier Brothers, 1888.

This well-known fitting, for supplying solid lubricant to a bearing, was patented in 1878 by Mr. B. Stauffer.

The cup for containing the lubricant (a sample of which is shown in a glass jar) is screwed internally to fit a disc formed with the nipple screwing into the bearing. Upon slightly turning this cup, or cap, some of the grease is forced into the bearing and in this way the lubricant is supplied at intervals while its viscosity prevents its flowing away. In a later form which is shown in section, there is a small spring-loaded piston on the cap, which gives a continuous supply and indicates when the cap requires to be screwed further home; the rate of feed is adjustable by an internal set screw which contracts the delivery passage. M.1895.

317. Sight-feed lubricator. Lent by Messrs. Sidney Moorhouse & Co., 1888.

This is an apparatus for automatically feeding drops of oil into the steam pipe of an engine, in order to lubricate the slide valve and piston. The simple form of displacement lubricator in which steam is admitted to a chamber containing oil, where it condenses and displaces the oil, causing it to overflow into the cylinder, was patented by Mr. J. Ramsbottom in 1860; in this form the feed depends entirely upon the rate of condensation in the chamber. The arrangement was subsequently improved by the addition of controlling valves and a glass tube filled with water up through which the drops of oil float so as to render the rate of feed visible.

The lubricator shown consists of a large oil chamber having a filling plug at the top and a cock at the bottom for draining off the accumulated water. The steam is condensed in a chamber at the top of a long vertical pipe and passes, through a controlling valve, into the bottom of the oil chamber. The displaced oil passes from the top of the chamber down an internal pipe which leads, through a valve, to a fine nozzle placed at the bottom of a glass tube attached to one side of the chamber. The oil floats up through the water in the tube and is led to the engine steam pipe, along which it is carried by the rush of steam. M.1892.

318. Self-acting lubricator. Received 1907.

This is an example of a positively driven lubricator patented in France by Mons. A. M. Mollerup in 1881. It is employed extensively on the Continent, and a modified form is now manufactured in this country.

It consists of a lower vessel to contain oil, fitted with a hollow plunger or piston, which is actuated by an arrangement of ratchet, worm and screw gearing. The upper end of the piston forms a nut for a square threaded screw which has a loose worm wheel on its upper end. This wheel gears with a worm driven by a ratchet wheel, the long ratchet arm obtaining its motion by its attachment to a reciprocating part of the engine. Thus at every stroke of the engine a slight turn is imparted to the square-threaded screw, and this, being fixed in position, causes the nut, *i.e.*, the piston, to descend and force out oil into the distributing pipe, which is attached to the upper part of the oil cylinder. The rate of oil feed can be adjusted to suit the requirements by moving a sliding block on the ratchet arm. When a wing nut above the plunger screw is tightened, the worm wheel and the screw rotate as one, but when this nut is loose, the worm wheel revolves freely on the screw and the plunger can be raised or lowered by turning the handle at the top of the lubricator.

To fill the lubricator, the wing nut is slackened, and the plunger is drawn to the top of its stroke. Oil can then be poured into the lower vessel through the cup at the side.

The rotation of the plunger is prevented by a piece of bent wire, U-shaped at its upper end, which is guided by a vertical fixed wire rod. The screw is only just long enough to allow the plunger to reach its lowest position and empty the vessel of oil; any further rotation then winds the screw out of the plunger. M.3496

319. Sight-feed lubricator. Presented by Messrs. Walter Lees & Co., 1903.

This is a sectioned example of the mechanical lubricator patented in 1893 by Mr. T. W. Lees by which the oil required is forced into the cylinder or bearing at a visible and adjustable rate by a small pump driven by the machine.

The apparatus consists of an oil reservoir from which, by an adjustable side orifice, the oil passes, in drops within a vertical glass tube, to a passage leading into a small ram pump. The ram extends upward into the reservoir, where there is an eccentric on a shaft slowly rotated by an external ratchet wheel, driven by a pawl on an adjustable lever rocked by the engine or shafting. The delivery valve of the pump is spring-loaded and serves also as a check valve, but a suction valve is dispensed with, as the plunger is arranged to overshoot, and thereby close the orifice admitting the oil into the barrel.

During the up-stroke the accumulated drops of oil sucked from the reservoir pass into the pump, to be forced out through the check valve during the completion of the down-stroke. M.3300.

320. Sight-feed lubricator. Lent by Messrs. John Smith & Co., 1896.

This is a modified form of feed lubricator patented by Mr. A. D. Ottewell in 1895. Like others of its class, it introduces oil in small quantities into the steam entering the cylinder, and so lubricates the internal working parts, while through a short glass tube each drop of oil supplied is visible, so that the correct rate of feed can be secured by adjustment, and the action of the lubricator can be inspected.

The apparatus consists of a large chamber containing the oil, and a smaller chamber above in which steam is regularly condensing. The steam condensed passes through an internal pipe to the bottom of the oil reservoir, displacing oil which escapes through a nozzle in the top of the reservoir into a short glass tube which is filled with water from the condensed steam; through this water the oil ascends in drops at a rate that is controlled by a valve at the side of the reservoir. The condensing chamber has a side passage controlled by a valve, through which the steam enters and also the oil escapes, the water-level in the chamber standing at the level of this outlet, so that any excess of condensed water will flow out into the steam-pipe, as will also the oil that, having risen through the glass tube, is floating on the surface of this water. When all the oil has been used, and the lower reservoir is accordingly full of water, the valves are closed and the water run out through a drain cock at the bottom of the reservoir, while a fresh supply of oil is introduced through the filling plug at the top of the reservoir. A sectional drawing of the apparatus is shown. M.2929.

321. Multiple pump lubricator. Lent by The Bosch Magneto Co., Ltd., 1912.

This is a sectional example of the forced feed lubricator patented by Mr. E. Woerner in 1908, and subsequently improved by the makers. The lubricator can be used for all kinds of machinery, and is arranged to supply

oil under pressure to from two to eight different points; each service has its own separate pump, and is provided with a sight-feed tube which is not under pressure. The oil supply is proportional to the speed of the machine, which itself drives the lubricator.

The pumps are arranged vertically in a circle round the driving shaft, each having a plunger and a piston valve, the latter being nearest to the shaft. The shaft carries at its upper end an inclined disc or swash-plate, the edge of which engages with notches cut in the upper ends of the valves, and so causes them to reciprocate once in each revolution of the shaft. Above the swash-plate is loosely mounted another disc, which has its edge in the form of two upper and two lower horizontal portions connected by inclines; this disc engages with notches formed in the heads of the pump plungers, and by its revolution causes them to reciprocate twice in each revolution of the shaft. The upper disc is set 45 deg. behind the lower one, and it is driven by a pin which engages with the ends of a slot cut in the boss of the lower disc; this arrangement allows the lubricator to be driven in either direction, the lower disc being allowed to set itself with the necessary lead. The valve and pump passages are so formed that during one downstroke of the plunger the oil is passed through the sight tube and returned to the oil chamber, while on the next downstroke it is forced out into the service pipe, each pump acting in turn as the shaft revolves. The quantity of oil delivered by each pump can be varied by means of a screw which alters the width of the notch in the plunger head; increasing the width decreases the stroke of the plunger. No packings are used on the plungers and valves. The pumps are mounted on a base plate which is supported from the cover of an oil-containing chamber, so that the whole mechanism can be lifted out with the cover. The oil chamber is filled through an opening in the cover fitted with a strainer; this opening is closed by a cap which also covers the ends of the pump adjusting screws. The pump suction pipes are provided with strainers, and the oil chamber is fitted with a transparent slot to show the oil level. The vertical shaft is driven by a worm wheel and a horizontal shaft fitted in the lower part of the oil chamber.

Each pump delivers from 0 to 0·2 c.c. of oil per stroke, and makes 10 effective strokes per min. The driving shaft is geared to run at either 250 or 500 rev. per min. M.4101.

322. Drip feed lubricators. Lent by Messrs. Best and Lloyd, Ltd., 1913.

Two semi-automatic drip feed lubricators, one of which is in section, are shown. They are of a simple form for motor cycle, etc., engines, patented in 1909 and 1911 by Mr. R. H. Carpmael.

The lubricator consists of an oil reservoir, a pump with a cup leather packed piston forced up by a spring, and a drip nozzle. On depressing the piston, oil flows past the cup leather, back suction being prevented by a ball valve. The pressure of the spring then forces the oil through the nozzle placed inside a sight glass tube, the rate of feed being regulated by a screw with graduated head. A catch is provided to hold the piston down when it is required to stop the flow of oil. The spring gives a pressure of about 10 lb. per sq. in. Inv. 1913–187 and 188.

Engine Packing.

323. Piston with metallic packing. Presented by B. Goodfellow, Esq., 1857.

This packing was patented in 1838 by Mr. Goodfellow. The two packing rings are bored conically internally, to correspond with an internal spring ring which has conical surfaces. The spring ring is turned somewhat eccentric, and is cut through, and, to give greater uniformity of action throughout its circumference, several deep radial notches are cut in its periphery. M.139.

324. Metallic piston packing. Presented by Messrs. Mather and Platt, 1858.

This form of packing was patented by Messrs. W. and C. Mather in 1846. It consists of an external cast iron ring flanged internally at the ends, and converted into a band by a helical cut, which goes twice round the ring, but terminates abruptly at each end. To prevent the passage of steam through the helical cut, a metal cover piece is fitted to the ring on each side. To expand this ring, both radially and endwise, a helical spring constructed somewhat like the external ring, but of smaller diameter, is prepared, and inserted within the true ring. A wooden model of a piston fitted with this packing is shown, together with the internal and external portions of the packing for a larger piston of this kind. The packing is inserted by providing the piston with a junk ring held down by set screws, and an enclosing band tightened by a set screw has been provided for compressing the spring when the piston is being entered into the cylinder. Inv. 1858–14 to 16.

325. Piston with metallic packing. Lent by Messrs. T. Bates & Co., 1888.

In this packing there are two split piston rings of L section, expanded radially, and separated longitudinally by about three turns of a single helical spring. The method of construction of this internal spring was patented in 1874 by Messrs. E. Wigzell, J. Pollit and W. Mellor, and consists in tapering a bar of spring steel to the required shape, winding it on a revolving mandrel, and tempering it in oil. A larger example of this spring is also shown, together with the clamp used to hold the rings while getting the piston into the cylinder. M.1899.

326. Metallic piston packing. Lent by Messrs. W. Buckley & Co., 1891.

This packing was patented in 1878 by Mr. W. Buckley. It consists of two equal steel rings, bored conically inside, and cut through at one spot, gun-metal cover pieces being fitted to prevent leakage between the ends of the rings. Between these rings is placed an internal ring, formed by coiling wire of rectangular section into a helix, flattening it, and joining the ends, after it has been bent to a circle, by a flat core. This ring, pressing on the inclined interior surfaces of the split rings, expands them radially, and also forces them apart longitudinally, so as to maintain a tight joint on the sides of the recess in the piston, as well as on the cylinder. M.2363.

327. Metallic piston rod packing. Lent by E. M. B. Faull, Esq., 1879.

A small example of this packing, patented by Mr. Faull in 1878, is shown as fitted to a piston rod 1 in. diam. The packing is arranged to occupy the usual stuffing box and to be tightened by the gland. It consists of a gun-metal ring with conical ends, divided by zigzag cuts into three segments. The segments are held by a brass ring at each end, which, being conically recessed, press the segments on to the rod when closed together by the gland. One turn of gasket packing is placed at the gland end to hold the lubricant. M.2510.

328. Metallic piston packing. Lent by Messrs. Lockwood and Carlisle, 1887.

This construction of packing was patented in 1881–4 by Mr. W. Lockwood. There are two split rings, bored slightly conical, and inside them are two sets of wire springs, one giving radial pressure and the other axial pressure. The radial pressure is exerted by flattened helical springs, made of round wire, and the axial pressure by gridiron springs placed between them. The different springs are combined alternately into a complete circle. M.1862.

329. Metallic piston packing. Lent by Messrs. Lancaster and Tonge, 1887.

This construction of packing was patented in 1884 by Mr. H. Lancaster. There are two split piston rings, each formed with an internal end flange, and between these flanges is a helical spring of round wire, bent to fit the circumference, and butt jointed. This internal spring exerts upon the rings both the radial and longitudinal pressures desired. M.1879.

330. Metallic piston packing. Received 1913.

This piston packing, patented in 1884 by Messrs. J. Qualter and E. Hall, has two piston rings coned on the inside and fitted with a correspondingly coned split ring. This is acted on by three leaf springs each forced out radially by a wedge behind it. Each wedge is set up by a locked set screw in the junk ring or cover which is held on by three screws.

The example shown is for a cylinder 4 in. diam. Inv. 1913–89.

331. Sectional model of Duval's metallic packing. Presented by J. B. Von der Heyde, Esq., 1901.

This shows a stuffing box and gland, for a piston rod 1·375 in. diam., packed with the metallic gasket patented in 1886 by Mons. A. P. Duval.

The packing is formed of brass wire, of No. 36 I.W.G., plaited into a square coil, from which lengths sufficient to form separate rings are cut and placed in the stuffing box so that they break joint. Such metallic gasket possesses considerable flexibility and is incombustible, while its interstices retain the lubricant; it is made in various sizes from 0·25 to 2 in. square. M.3176.

332. Rowan's piston packing. Lent by J. Hind, Esq., jun., 1891.

In this packing the radial pressure expanding the rings, and that securing the tightness of the rings against the sides of the recess in the piston, are obtained by independent springs.

Two rings cut and fitted with the usual joint cover piece are employed, the radial expansion being secured by a short and flattened helical spring acting between two abutments provided inside the rings on each side of the cut. The longitudinal pressure, forcing the rings tightly against the sides of the piston recess, is supplied by inserting between the two rings a "wave spring," formed by bending a flat bar of steel into a circle and then corrugating it. On screwing down the piston junk ring, these corrugations, or waves, are flattened to the extent necessary to give the requisite pressure. It is stated that a radial pressure of about 0·81b. per sq. in. is sufficient to prevent steam passing between the ring and the cylinder, but that a high longitudinal pressure is required to maintain the rings tight against their recess, depending upon the piston speed and the steam pressure. M.2418.

333. Metallic piston rod packing. Lent by Messrs. Mather and Platt, 1893.

This packing is so designed that it may be placed in stuffing boxes of ordinary construction, and be used to replace the fibrous packings so generally employed for piston and valve rods. It consists of a split cast iron casing, turned to fit the stuffing box freely, and provided internally with four deep grooves. In each groove are fitted two white metal rings cut through and breaking joint, the requisite elasticity for closing in being given by an encircling steel spring. In cases where packing cannot be slipped over the piston rod the white metal rings are formed in halves with overlapping joints, and the closing steel rings are also in halves, but dovetailed together. Rings

for both arrangements are shown. The packing is held in place by the ordinary gland, an india-rubber washer being added at each end to give flexibility. M.2531.

334. Piston packing. Presented by Messrs. Allen and Simmonds, 1908.

This is a piston fitted with a modern form of the metallic packing patented by John Barton in 1816; it embodies improvements patented by Messrs. R. and C. H. Allen and W. J. Wakefield in 1900.

The piston has two grooves turned in it, and in each of these a ring, formed of three cast-iron segments, is placed. The adjacent ends of the segments are bevelled, and between them are placed wedge pieces, which have turned stems fitting into holes in the piston, and are pressed outward by helical springs so as to expand the rings. The wedge stems are of larger diameter than the width of the rings, and they are carried up on each side of the inclines, level with the apex, so that a large surface is presented to the cylinder and scoring is prevented. A shallow groove is turned on the surface of each ring, and the segments in the two rings are arranged to break joint; the wedges have an angle of 125 deg.

The example shown is 8·5 in. diam. M.3585.

335. Piston rod packing. Presented by the United States Metallic Packing Co., 1902.

This packing was patented in 1893 by Messrs. W. E. Plummer and W. M. Kermode, and is a development of a form invented by Mr. E. Monroe in 1875. Its features are that it permits of free lateral and angular motion of the rod due to vibration, it is self-adjusting under wear, and its contact round the rod is chiefly derived from the steam pressure.

In the arrangement shown by the sectioned specimen the packing is of the duplex type, consisting of two separate sets of packing, the inner series partially resisting the steam pressure and the outer one completing the work.

The inner packing consists of three babbitt metal rings contained in a conical cup fitted with a gland which is forced home by springs assisted by the steam pressure. The front of the cup is free to slide on the plane face of a washer, the other face of which beds in a spherical recess on the stuffing box cover, while the gland end is free to slide on the plane face of another washer which is forced home by a number of helical springs, but the chief closing pressure upon the gland is that exerted by the steam. With the exception of the soft metal rings, the whole of these parts are bored much larger than the piston rod diameter.

The outer packing is similarly held endwise between flat and spherical faces kept in contact by springs assisted by the steam pressure, and so arranged as to give freedom for lateral and angular movement of the rod and its packing. The packing itself is, however, quite different, consisting of two rings each made up of gunmetal blocks and two blocks of babbitt metal, all forced inward by radial springs. The soft metal sectors break joint and also press upon the rod, while the gunmetal ones are quite clear of the rod; the reduced steam, moreover, which has passed the inner packing exerts a radial pressure upon these blocks which keeps them in closer contact with each other, and also presses the soft metal blocks upon the rod. Each babbitt metal block embraces one-third of the circumference of the rod, and as the four blocks break joint the complete circumference is thus fully covered.

It is claimed that, owing to the closing of the packing being automatically performed by the steam pressure, the arrangement works for many years without attention, and that wear is diminished owing to the pressure being relieved during the exhaust strokes. M.3247.

336. Model of metallic piston rod packing. (Scale full size.) Lent by the Combination Metallic Packing Co., Ltd., 1908.

This model represents the packing fitted to the high-pressure piston rods of H.M.S. "Hampshire," and is of the form patented by Mr. J. M. Robson in 1903.

The packing is of the duplex type, consisting of two separate sets of packing, the inner set being contained in the stuffing box and the outer one in an extension cap bolted on. The inner packing consists of white metal wearing rings, composed of a special alloy, made in segments and fitted within gun-metal cases or cups the lips of which telescope into one another. These cups have bevelled surfaces which bear upon corresponding surfaces on the packing rings, so that when axial pressure is applied to the cups by a number of helical springs placed at the inner end of the stuffing box, the packing is closed on to the rod with sufficient pressure to prevent leakage but not to cause undue friction. The cups are smaller in diameter than the inside of the stuffing box and they fit between flat surfaces so that lateral motion of the rod and packing is allowed. The outer packing consists of two floating segmental wearing rings held endwise by springs, between flat plates, while radial pressure is applied by surrounding split rings the free ends of which are drawn together by flattened helical springs. Lubricating oil is supplied to the space between the two packings. M.3562.

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337. Cylinder drain and relief valve. Lent by H. P. Holt, Esq., 1879.

This arrangement of valve, patented by Mr. Holt in 1878, combines in one fitting the drainage and relief safety valves for both ends of an engine cylinder.

Pipes from the two ends enter the casing shown, and the discharged water from the cylinder is carried off by a central pipe. In the casing is a valve for each end of the cylinder, and each of these valves consists of a central disc or relief valve, and also of a double-seated annular valve outside, which is the drain valve; these annular valves are kept on their seats by springs. The action is such that, when steam is in one end of the cylinder, its pressure opens the drain valve of the other end or exhaust side, while, at any time, the central or relief portion of the valve will open should the pressure, through priming, exceed the limit determined by the springs. M.2518.

Condensers and Air Pumps.

338. Model of McCarter's condenser. (Scale 1 : 6.) Lent by J. Wood, Esq., 1876.

This form of condenser was patented in 1869–73 by Mr. J. W. McCarter, and is intended to dispense with the usual air pump. It consists of a vertical cylinder that acts as an ordinary jet condenser. Below the condenser is a closed vessel into which the condensed water flows through a foot valve, and from which it is discharged by a delivery valve. Steam is admitted to this closed chamber by a valve driven by tappets on a rotating shaft above, so as to give six short admissions of steam per minute. At the same time that the steam valve is opened a similar delivery valve is opened, the air and condensed water being thus blown out by the steam. The arrangement is equivalent to using Savery's engine or a pulsometer in the place of the ordinary air pump. M.2508.

339. Specimens of Clarkson's atmospheric condenser. Presented by the Clarkson and Capel Steam Car Syndicate, 1901.

This construction of air-cooled condenser was patented in 1895 by Mr. T. Clarkson, and has been extensively adopted for condensing the steam or cooling the water used in motor cars, owing to the large amount of cooling surface it presents to the air in proportion to the weight of the apparatus.

The fluid to be cooled is passed through a central tube of thin copper, the specimens shown being 0·25 and 0·5 in. bore respectively, and the exterior of the tube has rolled into it a helical depression into which is wound a continuous helical spring, whose coils slightly interlock and are held into their bed by an internal wire wound with it. The whole tube, with its added radiating surface, is then dipped in molten tin, by which complete metallic contact is made between the tube and the wires, while increased rigidity is conferred by the connection which the tin establishes between the successive coils at their points of contact. The small diameter of the radiating wire gives great surface in proportion to its weight, while the high conductivity of the copper, together with the metallic connection, ensures that the heat is conveyed to the wire loops as fast as the large amount of freely exposed surface disperses it to the passing air.

M.3171.

340. Radiator tubes. Presented by the Lune Valley Engineering Co., 1907.

These are specimens of radiator or condenser tubes in which the cooling surface is increased by surrounding the tubes with wire coils constructed in the manner patented by Messrs. J. G. A. Kitchen and L. P. Perkins in 1903.

The thin copper tubes used are covered with a triangular helically formed coil of phosphor-bronze or aluminium wire, the ends of which are secured by soldered copper caps. The coil is formed by winding the wire closely upon a straight rectangular mandrel with rounded edges: this coil, when removed from the mandrel, partly unwinds and assumes a triangular form with the angles of each turn advancing upon those of the adjacent one. The internal diameter of the coil is somewhat less than the diameter of the tube, so that when slightly twisted it may be easily slipped on, and when released it securely grips the tube. It is claimed that no soldering or binding is necessary.

M.3476.

341. Aero-condenser. Lent by Mons. F. Fouché, 1907.

This is a condensing apparatus of the form patented by Mons. F. Fouché in 1880–1905, in which steam is condensed by passing it through passages of special form around which an opposite current of air is induced by a fan. It may also be used to heat air by means of exhaust or live steam for drying or ventilating purposes.

The apparatus consists of a rectangular sheet iron chamber, at one end of which is fitted a fan driven by an electric motor. Within the chamber are placed vertically a number of hollow plates, each consisting of two thin metal sheets fastened together at the edges, a short distance apart, thus forming narrow rectangular passages which expose a large surface to the air current. These plates are connected together, with the steam inlet at one end and with the outlet at the other end, the steam flowing in the opposite direction to the air. At the connection each plate has a circular orifice surrounded by a concentric projection on one sheet and a corresponding depression on the other, and between the two sheets is inserted a perforated ring which supports the joints while allowing the steam to pass through the plates. Between each pair of plates suitably shaped distance rings are placed and closing washers over the holes in the outside members of the group; the plates and rings are then drawn tightly together by bolts passing through the connecting holes, jointing material being introduced if necessary. The sheets forming the hollow plates are stayed at intervals by being stamped inward to meet and riveted together.

The small specimen shown will deliver 350 cub. ft. of air per min., with the fan running at 2,000 rev. per min.; it will condense 35 lb. of steam per hour and raise the temperature of the air from 60 deg. F. to 124 deg. F. when

working without a vacuum, or 22 lb. of steam and an air temperature of 100 deg. F. when working with a vacuum. M.3471.

342. Model of Leblanc air pump. (Scale full size.) Lent by The British Westinghouse Electric and Manufacturing Co., Ltd., 1910.

This is a form of rotary air pump, patented by Mons. M. Leblanc in 1905 and 1907; it is simple in construction and is capable of producing a high vacuum, such as is required in the condenser of a steam turbine where a large ratio of expansion is necessary for high efficiency.

The pump consists of a cylindrical casing containing a turbine wheel, through which water flows radially outwards from a port or nozzle. This nozzle is mounted on a disc so curved as to give an easy passage to the water, which enters the casing by a pipe on one side of it. The shaft passes through stuffing boxes at each side, and outside these are the bearings supported by extensions of the casing. A pipe, formed in one with the main casing and placed tangentially to it, is connected with the condenser at its upper end, and contains a converging tube close to the wheel, while a diverging discharge pipe is fitted to its lower end. The wheel is rotated at a high speed, usually by a directly connected electric motor, in the opposite direction to which it would rotate if driven by the water, and it throws the water from the nozzle into the diffusing cone in a succession of thin sheets having a high velocity. These sheets completely fill the tube, entrap between them the air and non-condensable gases coming from the condenser, and carry them out against the atmospheric pressure. A steam ejector is fitted to the discharge pipe to start the pump.

The pump wheel is 15 in. diam., the air inlet 4 in. diam., and the water inlet 5 in. diam.; a pump of this size is suitable for a condenser dealing with 15,000 cub. ft. of steam per hour. It will produce a vacuum of 28·5 in., with cooling water at 15 deg. C., and runs at 960 rev. per min., requiring an expenditure of 9·5–10 brake h.p. M.3756.

343. Model of Edwards's air-pump (working). (Scale 1 : 4.) Made in the Museum from drawings supplied by Edwards Air Pump Syndicate, 1904.

In this construction of air pump for a condensing steam engine, which was patented in 1894 by Mr. F. Edwards, there are neither foot nor bucket valves, a simplification which reduces the vertical height of the pump and increases the practical working speed.

The pump is either attached to the side of the condenser and driven by rocking beams or is entirely separate from the engine and driven by an overhead crankshaft combined with it. The lower opening into the casing communicates with the bottom of the condenser while the upper one leads to the hot-well; a side door near the top gives access to the delivery valves, and there is a safety valve to prevent any pressure accumulating when "blowing through," or if the condenser should become hot.

The cover of the casing has a gland for the pump rod, but the use of a second gland is avoided by prolonging the stuffing box downward till it makes a joint with the internal cover carrying the delivery valves. The working pump barrel is a separate liner fixed to and supported by the casing.

The bucket of the pump is a complete piston which during its down-stroke is forming a vacuum above it, but when nearly at the bottom of its stroke, it passes over radial ports through the barrel, through which passages the water and air from the condenser rush into the vacuum above the piston; the piston at the same time acts as a displacer in removing the fluids accumulated below it to its upper side. In the following up-stroke these fluids are discharged through the delivery valves in the cover as the piston approaches the top of its stroke; the piston is not packed, except by the water upon it,

and the clearance volume at the top of its stroke is small. The bottom of the piston is made conical to avoid shock when displacing the water beneath it, and, owing to the way this water is thrown on to the upper side of the piston and there entrapped, the arrangement will work even without valves. The valves are of the disc type and are water sealed, but they can be easily removed or replaced even when the pump is at work. M.3358.

344. Air pump valves. Lent by the Metallic Valve Co., 1889.

Mineral lubricating oil has a solvent action on india-rubber, and its introduction has led to the disuse of that material for air pump valves. Flexible metal clacks held at one edge by set screws were introduced in 1848 by Edward Humphrys, but had a tendency to breakage at the line of flexure. This is avoided by the use of the curved guard shown, which at the same time holds the clack along a diameter, as patented in 1878 by J. G. Kinghorn and W. J. Coe. The clack is of copper or phosphor-bronze sheet, often elliptical in shape, and rests on a suitable grating.

In another form there are several thin discs of the same metal of decreasing diameters loose on a central stud and lifting against a flat guard. Usually each disc except the top one is perforated, the next one below on the grating acting as a seating for it. They close independently, so reducing shock. M.2268.

345. Thomson's air pump valves. Presented by Messrs. Steven and Struthers, 1899.

These valves are annular, and resemble arches springing from the inner to the outer seatings; a few radial ribs give additional strength. The arrangement forms a strong and light valve, with double passages if desired; it has been chiefly used in engine air pumps. M.3056.

346. Dead-lift valve. Presented by T. Downie, Esq., 1910.

This form of valve, for air or water pumps, was patented by Mr. Downie in 1901. The valve is stamped from sheet metal, and has a long boss at the centre which acts as a guide, and a turned-up edge which stiffens the valve and allows water to accumulate, thus forming a cushion. A central stud projects from the valve seating, and on this a flat guard-plate is fixed to limit the lift, it being bored out to accommodate the valve boss. M.3789.

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347. Drawing of an intermediate receiver. Lent by E. A. Cowper, Esq., 1887.

This is a steam-jacketed vessel, commonly called "Cowper's hot-pot," for receiving the steam after it has been used and expanded in the high pressure cylinder of a compound engine, and before it passes to the low pressure cylinder; then, when the cranks have moved 90 deg., the steam passes out to the low pressure cylinder, and in doing so is obliged to pass outside a lining and in close contact with the hot steam-jacketed vessel, thus becoming somewhat warmed up; it is then used and expanded in the low pressure cylinder, thus allowing of a large amount of expansion and consequent economy. The cranks are placed at 90 deg., and the steam is cut off before half stroke in the low pressure cylinder, so that a second charge of steam is not allowed to enter it in the middle of the stroke. The receiver was first introduced in 1857, and the internal lining was added in 1862. M.1876.

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348. Steam-quieting chamber. Lent by G. Beck, Esq. 1879.

This apparatus for reducing the noise of the exhaust from a high-pressure steam engine was patented by Mr. T. Shaw in 1875, but it has been much more extensively applied to gas engines.

It consists of a cylindrical chamber arranged vertically, and provided with grids near the upper and lower ends. From the grid to the top of the chamber the space is filled with glass beads, marbles, or pebbles, so that the discharged steam, delivered into the space below the grid, in passing up through the small interstices is hampered, and the sharpness of its exhaust reduced. M.2509.

STATIONARY BOILERS.

The simplest method of heating a liquid is obviously in a cauldron over an open fire; that the wastefulness in fuel of this means of heating may have been realised at an early date seems to be evidenced by bronze vessels discovered at Pompeii; these embody an internal firebox and water-tubes.

At the time of the introduction of the steam engine the closing in of the grate and the addition of flues in masonry was already common in the externally fired open "coppers" used by brewers, sugar refiners, &c. Savery, in 1702, refers to this practice; apparently he made his boilers spherical, or cylindrical with domed ends, but as his apparatus required steam at a pressure of three atmospheres or more, it is not surprising that, in the then state of the arts, he found the difficulty of making a satisfactory boiler almost insurmountable. The Newcomen engine which came into use a few years later required steam of atmospheric pressure only, so that by covering in the top of a copper—sometimes simply with a sheet of lead—the haystack type of boiler (*see* No. 349) was arrived at. Hammered iron plates, with riveted joints, as the constructive material, appear as early as 1725. As heating surface was practically the sole requisite of a boiler, James Watt, about 1780, increased this by elongating the haystack type, so producing the wagon boiler (*see* No. 350) to which a few years later he added an internal flue. With the addition of a few stays, this boiler remained in use till about 1850.

The externally fired cylindrical egg-ended boiler, while of better shape than the two already mentioned to resist internal pressure, is like them lacking in heating surface. In spite of this, it was for quite 100 years an accepted type for pressures up to 30 lb. By adding to the cylindrical boiler an internal flue, the Cornish type, used by Richard Trevithick and Oliver Evans at the end of the 18th century, was reached. The former was one of the first to exploit the use of high pressure steam and in his portable engines (*see* Nos. 109 and 351) and his first locomotives he returned the flue inside the shell. As working pressures increased, the cylindrical type underwent many modifications, as in the elephant boiler (*see* No. 355), but a great step in advance was made in 1844 by Sir William Fairbairn who, seeing that it was proper to increase the number rather than the size of internal flues, introduced the Lancashire boiler. As pressures and dimensions again increased, these internal flues gave trouble owing to the danger of collapse, but this difficulty has been overcome by the addition of cross tubes (*see* No. 359), strengthening rings, and joints, or by the use of corrugated flues, so that such boilers are now working at nearly the highest pressure demanded, while in economy they remain unsurpassed. A successful modification, known as the Yorkshire boiler, was introduced in 1907. It is shorter than the

Lancashire type, its length being only two and a half times its diameter, while the furnace tubes increase in diameter from front to back in the proportion of two to three.

The vertical boiler, so generally used for supplying steam to small engines was suggested in a patent obtained in 1791 by Nathan Read; the modern form was patented in 1826 by James Neville. In recent years much has been done by the introduction of tubes, combustion chambers, &c. (*see* Nos. 360–4), to increase the efficiency of this, at one time wasteful, type of generator.

The high pressure multitubular boiler was brought to a practical success by Robert Stephenson and Henry Booth in the "Rocket" of 1829. At first the flat-sided water-jackets of the firebox were separate from the boiler, but soon the firebox was incorporated with the shell, and this has since remained the typical locomotive boiler. Owing to its compactness and great power in proportion to its weight, this type of boiler is employed with portable and semi-portable engines (*see* No. 981).

The idea of dividing the heating surface into small elements occurred at an early date, hence we get the water-tube and its analogue, the sectional boiler. These have the advantages that they can raise steam rapidly, can be forced, can be designed to stand almost any desired pressure, are comparatively immune from breakdown, and are of great power in proportion to weight. As the water content is small, close supervision in working is necessary. Such boilers are by no means new, however, but success has been delayed owing to lack of proper materials and to difficulties in workmanship rather than for other reasons. For example, James Blakey in 1766 patented inclined water-tubes, and in 1788 James Rumsey, among other ideas, suggested a coil boiler. In 1803 Arthur Woolf introduced successfully a multiple tube boiler. For a steam launch in 1804 James Cox Stevens made a "porcupine" boiler that is still preserved. The introduction in 1820 of steam carriages for common roads gave a great impetus to the invention of pipe and sectional boilers, among which may be mentioned those of Goldsworthy Gurney, Church and Hancock. Development was arrested, however, in 1835, owing to legislative action. In 1825 Joseph Eve brought out the first water-tube boiler with a well-defined circulation, provided for by means of external down-comers. Stephen Wilcox in 1856, first used tubes at a slight inclination to the horizon connecting water spaces at the front and rear, a type that has proved persistent in subsequent development (*see* No. 372). The idea of promoting circulation by placing one tube centrally within another originated in 1862 with Edward Field (*see* No. 365) and has been developed by Niclausse, 1891–1900 (*see* No. 374). The coil boiler has recently received attention. In fact, development is most active in boilers of the water-tube type.

The flash boiler, in which steam is generated by spraying pure water upon red-hot metallic surfaces, was proposed in 1736–41 by John Payne. From 1823 onwards Jacob Perkins

experimented by pumping highly heated water as required through red-hot bars, thus superheating the steam produced. He attained to pressures of 1,500 lb. Léon Serpollet's boiler, which he designed in 1887 and applied to motor cars, is the best known modern example (*see* No. 375).

Notwithstanding the great variation in the construction and proportions of boilers now in use, the difference in their efficiencies is comparatively slight. The weight of water evaporated from and at 100 deg. C. per pound of good coal in ordinary work is between 7 and 9 lb., while the heat generated by such coal would be equal to an evaporative power of about 13 lb., giving, therefore, a boiler efficiency of from 50 to 70 per cent.

349. Haystack boiler. (Scale 1 : 12.) Made in the Museum from particulars supplied by the Coalbrookdale Company, 1907. Plate VII., No. 1.

This type of boiler, which, together with its setting, was only an adaptation of existing practice with brewers' pans and spirit stills, was used throughout the 18th century for supplying steam to atmospheric engines; under the name of the "balloon" boiler it survived in the Staffordshire district till late in the 19th century. The period represented by the model is about the middle of that century.

At first it was the practice to place the boiler vertically under the engine cylinder, but about 1760, as the power of engines was increasing, the demand for more steam was met by an increase in the number of the boilers, placed in contiguous settings, rather than in their size. The boiler was under-fired and set in masonry or brickwork, so that the hot gases made a complete circuit of the sides on their way to the chimney in a way known as a "wheel draught."

As the pressure used was practically only that of the atmosphere, the question of construction was subsidiary to that of heating surface; accordingly we find that the flange boiler, which was the type used with the earliest Newcomen engines, had the side flue formed by a horizontal flange uniting vertical sides to a domed top. Later a slight improvement was made by adopting conical or concave sides, hence the name "haystack." The bottom was at one time recessed so as to form a spiral flue, as patented in 1748 by Thomas Stephens and Moses Hadley, but generally it was flat or concave. Internal stays were but rarely used, and instances of boilers up to 15 ft. diam. without them are recorded. The numerous explosions that have been traced to these defects in shape and construction, and the low ratio of heating surface to cubic contents possible, led to the disuse of this type of boiler.

The material of which the boiler was made was at first copper, often with lead for the top; the corners appear to have been made by flanging the plates. On account of their durability and less cost, wrought-iron plates produced by hammering seem to have been substituted as early as 1725. Cast iron was also used; even in 1776 Smeaton preferred this material for his boilers. It was not till about 1790 that plates and other sections produced by rolling became generally available.

The feed water was introduced through a valve controlled by hand into a cistern on a vertical stand-pipe by which a column of water of sufficient height to balance the pressure within was obtained. The water level was indicated by the position of a lever connected with a float inside. The blow-off pipe was usually stopped simply by a wooden plug.

The model represents a boiler 11 ft. high by 12 ft. diam. at the dome, decreasing to 10 ft. diam. at the bottom. The grate area is 25 sq. ft., the heating surface 235 sq. ft., the water space about 550 cub. ft., and the steam space 300 cub. ft. The pressure would not exceed 3 lb. per sq. in. M.3502.

350. Model of wagon boiler. (Scale 1 : 12.) Made in the Museum, 1901. Plate VII., No. 2.

This type of stationary boiler succeeded the haystack form (*see* No. 349), and was a considerable improvement in that it possessed greater heating surface and grate area, while being easier of construction. It was introduced by James Watt about 1780–90, and remained in general use till about 1850, when the gradual increase that had taken place in boiler pressures led to its abandonment through the inherent weakness of its shape.

The boiler usually had a semi-cylindrical top with concave bottom and sides, and was set over the furnace, from which the gases, after passing along the bottom to the end, returned along one side flue, and then passed back again by the other side flue, following the course known as a "wheel draught." At a later period a nearly square central flue through the boiler was introduced, and the gases from the furnace, after passing under the bottom, returned through this flue, dividing at the front, so that one half of the quantity passed along each of the side flues, thus originating what is known as the "split draught." The feed water was introduced by a vertical standpipe, or "feed-head," of sufficient height to prevent water being blown out of it by the steam pressure. In this pipe was a float connected with a damper in the main flue, so that if the pressure fell, the rate of combustion was automatically increased; the feed water was supplied to the head from a cistern provided with a valve controlled by a float within the boiler.

The boiler represented was of 20 nominal h.p. It was 13·8 ft. long, 6·8 ft. high, 5·33 ft. wide at the water line, and had a heating surface of 200 sq. ft., a grate area of 20 sq. ft., and ordinarily contained 300 cub. ft. of water, and had a steam space of 115 cub. ft. The pressure would be 5 lb. per sq. in.

M.3174.

351. Trevithick boiler. Received 1881. Photograph of similar boiler with engine. Presented by F. W. Webb, Esq., 1890.

This is a form of the return flue boiler which, combined with a high pressure engine, was patented by Trevithick and Vivian in 1802, and subsequently extensively used for locomotives as well as semi-portable engines.

The boiler shell is of cast iron 1 in. thick, 3·6 ft. diam., and 5·5 ft. long; the back end, which is dished, is cast with it, while the front of the shell has a flange to which the wrought iron front of the boiler is secured by bolts. To this front the two ends of the return, or horseshoe, flue are riveted; the larger leg of the flue is 18 in. diam., and holds the grate, the return portion being only 10 in. diam. The front of the boiler also has a manhole, but the system of construction rendered the whole interior readily accessible for scaling and repairs, owing to the ease with which the boiler front and furnace could be removed.

The steam generated passed into a cast-iron steam dome, surmounted by a 2 in. lever-weighted safety-valve, from which it was led by an external pipe to the valve chest of the steam cylinder, which is 9·5 in. diam. by about 36 in. stroke. The cylinder is arranged vertically, and is steam jacketed, being almost immersed in the boiler to which it is secured by an upper flange. The boiler steam, after passing through a stop valve of the plug type, is admitted alternately to the two ends of the cylinder by a four-way plug valve worked by a tappet motion.

The general arrangement of an engine and boiler of this type, supposed to have been made in 1803–4, can be seen by the adjacent photograph, which shows them restored and completed. The crankshaft extends below the boiler, and is driven by two return connecting rods from the crosshead.

M.1514 and M.2357.

352. Model of egg-ended boilers. (Scale 1 : 18.) Presented by Messrs. J. and J. W. Pease & Co., 1862.

These were formerly part of the large model of the self-acting incline at Upleatham (*see* Catalogue, Part II.).

The type of boiler shown remained in use later than the wagon boiler, when the increase in steam pressures rendered flat and badly stayed surfaces dangerous. It consists of a cylindrical shell with hemispherical ends, and is fixed over a grate formed in a brickwork setting, leaving flues for the passage of the flame and gases round the boiler on their way to the chimney. M.1410.

353. Models of brick settings for boilers. (Scale 1 : 16.) Contributed by R. Bodmer, Esq., 1861.

The boilers are of the externally fired egg-ended type. One model shows a form of setting tested in some boiler trials made by Mr. J. Graham in 1858. The flame and gases from a grate, of 34 sq. ft. area and 14 in. below the boiler, pass along a semi-annular flame space, 6 in. deep, straight to the chimney. It was considered that this setting was 30 per cent. more efficient than a similar setting with a deep flue.

In the other model the gases pass, from the furnace, along the bottom of the boiler, then return by one side flue, and finally proceed to the chimney by an opposite side flue, following a "wheel draught" (*see* No. 349). Air which has been heated while passing through brick flues formed in the surface walls is delivered at the bridge to complete the combustion of the gases from the furnace; this device was practically tested with some success in 1810 by Mr. John Wakefield, and has since been frequently re-invented. M.539–40.

354. Model of horizontal boiler on yielding supports. (Scale 1 : 16.) Lent by Jeremiah Head, Esq., 1876.

By this method of supporting a long boiler, patented by Mr. Head in 1870, the ends may rise and fall by expansion without altering the position of the points of support, thus reducing the stresses that frequently cause seam-rips.

The boiler represented is of the long egg-ended type in an ordinary brick setting, such as is still used in iron works. Pieces of T iron are riveted to the boiler and attached by suspension rods to weighted levers, with their fulcra carried on cast-iron bridges, two intermediate bridges, however, carrying suspension rods fixed by nuts. The steam connections are fitted with double bends or U pipes. By a hand wheel on the model the boiler may be curved so as to show the action of these supports. M.1424.

355. Model of elephant boiler with step grate. (Scale 1 : 12.) Made in the Museum, 1914.

The form of externally fired steam generator known as the elephant or French boiler consists of a main steam drum with one or more water drums, parallel to it below, connected by cylindrical necks and set in brickwork with a to-and-fro or an up-and-down draught. Constructionally the form is as strong and nearly as simple as the egg-ended boiler (*see* No. 352), but has greater heating surface for the same volume. The type was developed about 1820 from a somewhat similar construction patented and introduced in 1803 by Arthur Woolf. It was used in this country at one time as a mill boiler, but was superseded by the Lancashire boiler. The highest development has been reached on the Continent, especially in France, hence one of the names by which it is known here. It remains still an accepted type on the Continent, but is now being displaced by the water-tube boiler.

The step grate for burning fuel of low calorific value was introduced in Germany about the middle of the 19th century. It consists of a succession of flat bars stepped one in front of the other terminating in a fixed flat grate, the fuel being introduced by a hopper at the top.

The model shows a boiler installation made by A. Leinweber & Co., of Gleiwitz, for a pressure of 120 lb. The steam drum is 1·4 m. (4·6 ft.) diam. and 11 m. (36·1 ft.) long, its thickness being 11 mm. (0·43 in.) except over the fire where it is 12 mm. (0·47 in.); the ends are dished and are 15 mm. (0·59 in.)

thick. The two water drums are 750 mm. (2·46 ft.) diam. by 9·1 m. (29·9 ft.), their thickness being 7 mm. (0·27 in.). They are supported on cast-iron stools at a slope of 1 in 32 to the blow-off cock. The heating surface is 70 sq. m. (752 sq. ft.).

The grate is formed of flat plates resting in ledges on side and intermediate bearers, leaving air spaces of about 1 in. measured vertically. The angle of the grate is 35 deg.; these proportions are for wood chips and sawdust, which is the fuel used. The flat grate is of the usual construction and is cleaned through a door in the side wall. The total grate surface is 3·27 sq. m. (35 sq. ft.), *i.e.*, in the ratio of 1 : 21·4 of the heating surface. The fire bridge projects over the grate with the object of preventing smoke. The gases are directed up and down by vertical baffle walls situated closer together as the chimney flue is approached. Inv. 1914–397.

(*See* Herre, "Die Dampfkessel," 1906, pl. 11, p. 276.)

356. Model of Coleman's double boiler. (Scale 1 : 16.) Lent by Messrs. Coleman and Morton, 1879.

This is an experimental model of a boiler patented by Mr. H. S. Coleman in 1876, consisting of two horizontal shells fixed vertically above each other and connected by seven large necks. By a long internal tube in each alternate neck, communication is made between the bottom of the upper shell and the lower portion of the lower one. When in action, the water heated in the lower vessel rises through the necks, while the cooler water circulates downward through the internal tubes. The steam generated forms in the upper portion of the top chamber, and then passes into a small separating vessel fixed at the top. Glass ends have been fitted by which the circulation of the water can be observed. The boiler is mounted in a metal setting provided with two side doors, through which the heating surfaces can be cleaned. Between the two shells two horizontal plates are fitted, the lower one leaving a space at one end of the boiler and the other a space at the opposite end, thus forming flues through which the gases from the furnace below pass backward and forward and backward again before reaching the chimney. M.2504.

357. Model of Cornish boiler and setting. (Scale 1 : 12.) Made in the Museum, 1903, from information supplied by Livet's Boiler and Furnace Co.

The boiler has a single furnace flue, and is carried in a setting provided with flues which give a "wheel draught" (*see* No. 350). The special arrangements illustrated by the model are, however, the construction of the furnace bars and the setting patented by Mr. F. Livet in 1878. The bars are made of wedge section about 12 in. deep, for the purpose of warming the air passing through them; while, to avoid breakage from unequal expansion, each bar is composed of a separate upper and lower portion. The boiler is supported on cast-iron cradles built into a continuous mid-feather wall, there being thus only two external flues; the gases pass through these flues in succession, and the section of the flues increases as the chimney end is approached. The flues are made of exceptionally large dimensions, with the object of retaining the hot gases for a longer time than usual in proximity with the boiler shell; their size also reduces the chimney draught required, and facilitates cleaning and inspection. M.1739.

358. Drawing of a Lancashire boiler. (Scale 1 : 24.) Lent by Messrs. D. Adamson & Co., 1874.

This represents a pair of Lancashire boilers, each 7 ft. diam. and 24 ft. long, with two flues 33 in. diam. reduced to 28 in. at the further end. The whole of the fittings and arrangements of such boilers are clearly shown

including the automatic low-water alarm, double dead-weighted safety-valve, internal distributing pipe for the feed-water, and perforated collecting pipe for taking the steam from the highest part of the boiler. The plant was put down at the Vienna Exhibition of 1873.

The furnace is formed in short lengths of welded tube with the ends flanged out by rolling; this construction, known as Adamson's flanged seam, greatly strengthens the flue against collapse, and permits of joining the lengths without exposing the rivet heads and thick portion of the joint to the flame. Eight cross tubes, for increasing the heating surface and circulation of both the water and the gases, are welded into the flue beyond the fire.

The drawing also shows the method of setting and the brickwork flues employed. The weight of the boiler is carried on two fire-brick ledges, and the flues throughout have a fire-brick lining. The gases, after traversing the two furnace flues, pass downward and along towards the front by a wide flue directly under the boiler, and at the front the current splits and returns along the two side flues in two streams, which unite again at the base of the chimney. M.2482.

359. Model of a Galloway boiler and setting. (Scale 1 : 12.) Made by Messrs. Galloways, Ltd., 1894. Plate VII., No. 3.

This represents in section a Lancashire boiler of the "Galloway" type. Two furnaces 2·8 ft. diam. unite in one flattened tube 6 ft. wide and 2·75 ft. high, forming a combustion chamber which is the feature of the Galloway boiler. To give the necessary resistance to the collapsing pressure, thirty-three Galloway water tubes are introduced, the shape of the chamber enabling tubes to be used in which the flanges are perpendicular to the length. To deflect the gases amongst the tubes, four water pockets are inserted in the sides of the chamber. The furnace flues are welded longitudinally and united transversely by the Adamson flanged joint (*see* No. 358). The shell is in rings, each of a single plate, lap-jointed and double riveted, and the ends are each of a single plate. The front end is secured to the shell by a welded angle ring and gussets, and the back end by flanging it over and by the use of gusset stays. A 4-in. dead-weight safety-valve is fitted, and also a combined high-steam and low-water safety-valve. The actual boiler is 28 ft. long by 7 ft. diam., and is capable of evaporating 6,000 lb. of water per hour, giving 300 h.p. with a good engine. M.2577.

360. Drawing of vertical boiler. (Scale 1 : 4.) Presented by Messrs. A. Verey & Co., 1875.

In this arrangement of boiler, patented in 1867 by Mr. T. Messenger, a certain amount of tube surface is introduced. From the inner sides of the firebox project curved tubes reaching to the top, while in the central space is a baffle block to deflect the flame amongst them. A curtain of sheet iron is placed in the water space to increase the circulation, while "heat pegs" or studs projecting into the flame space are added, and these are stated to have a heating surface of equal value to that of the sides of the box.

M.2913.

361. Sectional model and drawing of Richardson's vertical boiler. (Scales 1 : 8 and 1 : 4.) Lent by Messrs. Robey & Co., 1874.

This is a vertical boiler patented by Mr. J. Richardson in 1873, in which considerable tube surface is introduced. The shell of the firebox is much larger than the grate, and from the space between them, nearly vertical tubes pass upward to the crown of the firebox. These tubes connect with the water space at each end, so that a good circulation of water is secured.

From the crown of the firebox the hot gases pass through nearly vertical tubes to the top of the boiler, where by a chimney with a large conical base the waste gases are collected and carried off. In this boiler, therefore, the two sets of tubes act in the reverse manner. M.2503.

362. Original sketch, and model (Scale 1 : 2) of Cochran boiler. Lent by Messrs. Cochran & Co., 1913 and 1881.

The pencil sketch shows Mr. Edward Crompton's original idea for embodying some features of the horizontal multitubular boiler in a vertical boiler which he and Mr. J. T. Cochran patented subsequently in 1878.

The firebox is of hemispherical form, so as to avoid flat surfaces which have to be stayed. From the firebox the burning gases escape through a circular opening to a combustion chamber above, and from thence pass through a number of short horizontal tubes into the smokebox on the opposite side, from which they escape into the chimney. It is found that these short tubes are much more efficient than their limited length and surface would suggest. The boiler is built of mild steel, and the model shows fully the details of the method of construction adopted. To prevent radiation of heat from the combustion chamber a fire-brick lining is fitted, and to facilitate cleaning the tubes the smokebox is provided with hinged doors.

In the model the surfaces in contact with the water are coloured dark blue, and those with the hot gases red. A modified form of this boiler is shown in the Marine Engineering Section. M.2814 and M.2505.

363. Models of Blake's multitubular vertical boiler. (Scale 1 : 12.) Lent by Messrs. Richardsons, Westgarth & Co., 1901.

This construction of vertical boiler embodies several arrangements patented by Mr. J. Blake between 1878–97. The shell is cylindrical, with a domed top containing the manhole; the firebox is in the form of an oblique cone, fitting the shell at the bottom and inclining to the back where it is connected with the base of a cylindrical combustion chamber having a dished top. These forms avoid the use of stays and therefore facilitate cleaning. The combustion chamber is completely surrounded by water, and from its front seventy horizontal fire tubes extend radially to the shell which is bossed out, where necessary, to receive normally those tubes which would pierce it obliquely. The grate is fired through a short oval tube connecting the firebox with the shell, while the smokebox, which is attached to the shell higher up and carries the chimney base, is provided with hinged doors for use when cleaning the tubes.

A separate mid-length section of the boiler shows an alternative arrangement of the combustion chamber and tubes. The chamber has a domed top and cylindrical back, which is stayed to the shell; the tube plate is flat, as is also the corresponding portion of the shell plating, so that the fire tubes are of uniform length and parallel; there are seventy-seven of these tubes, of which fourteen are provided with nuts so that they serve as stay-tubes.

M.3209.

364. Models of multitubular vertical boiler. (Scales about 1 : 8 and 1 : 12.) Lent by Messrs. Clarke, Chapman & Co., 1903.

The larger model shows an arrangement of boiler patented in 1898 by Mr. J. B. Furneaux. The shell is cylindrical with a closed segmental top, and the firebox is a truncated cone surmounted by a vertical cylindrical combustion chamber having a dished top. The cone is crossed by a large inclined water-tube, while from one side of the combustion chamber 130 fire tubes, arranged in vertical rows, extend radially to the shell. The ends of some of

the tubes are contracted by ferrules to ensure equal distribution of the gases, which pass through them to an external smokebox carrying the funnel and provided with sliding doors to facilitate tube cleaning. Three small tubes, passing radially from the outside shell, admit warm air directly into the combustion chamber to prevent the discharge of smoke or unconsumed gases. The shell of the boiler is extended downward to form the sides of the ash pan; the grate, however, is not shown.

The smaller model represents a modification of this arrangement patented in 1899 by Messrs. J. B. Furneaux and W. A. Woodison. The combustion chamber or flue tube is divided halfway up by a horizontal diaphragm of fire-clay, so notched that it can be passed up from below and then rest on ferrules projecting from some of the tubes. In this way the hot gases are caused to pass through the lower rows of tubes to the smokebox on the outside, whence they return through the upper rows to the flue and pass out by a central chimney. There are ninety-six of these tubes arranged in vertical rows, but the whole circumference is not occupied, two spaces being left for scaling purposes, and the smokebox is formed in two portions.

M.3302.

365. "Field" boiler tube. Presented by Messrs. Merryweather & Sons, 1903.

This is an example of the double water-tube for steam boilers, patented in 1862, by Mr. E. Field and Messrs. M. and R. M. Merryweather. By them it was applied to the boilers of steam fire-engines, in which lightness and rapid steaming are of great importance. This was the first practical application of an internal tube within a heated one for separating the currents of hot and cold water from one another.

The arrangement consists of an inner and an outer tube—the outer one, which is closed through its lower end being welded into a hemispherical shape, has its upper end expanded into the tube plate so that its exterior is exposed to the fire or hot gases; the inner tube is open at both ends and its upper end is provided with an enlarged mouthpiece, which projects above the tube plate into the water space and has three external fins supporting it centrally within the outer tube.

The water between the two tubes, becoming heated and giving off steam, rapidly rises and is replaced by cold water which flows downward through the central tube; the enlarged mouthpiece acts as a deflector in reducing priming, and also facilitates the entry of water into the down tube. In the Niclausse boiler and other developments of the concentric tube arrangement the rising and downcoming tubes open into separate chambers to avoid any interference between the ascending and descending currents. M.3282.

366. Models of corrugated flues. (Scale 1 : 12.) Lent by Samson Fox, Esq., 1879.

These show the form of furnace flue patented by Mr. Fox in 1877. The plain cylindrical furnace subjected to collapsing pressure showed its instability as pressures increased, and many devices were resorted to for the purpose of preventing its distortion and consequent collapse. Mr. Fox's invention has been very extensively adopted, and it is claimed that, in addition to the increased strength obtained, the flue will easily alter in length without requiring any separate expansion rings, and has also an increased heating surface.

These flues are made as plain cylinders, and then corrugated by rolling or by swageing, short cylindrical ends being left for making the necessary joints. The corrugations stiffen and strengthen the tube against collapse in the same way that a plate of metal used as a column would be strengthened if rolled with the Z section, so increasing the least moment of inertia. Galloway tubes corrugated longitudinally are also shown. M.2506.

367. Model of boiler flue. (Scale 1 : 8.) Lent by the Premier Boiler Tubes, Ltd., 1905.

This arrangement of water tubes for the internal flues of cylindrical or shell boilers was patented in 1901–3 by Mr. W. McG. Greaves.

About half the flue rings situated nearest the back end of the boiler are modified by having flats pressed upon so as to take a nest of solid drawn tubes 2 to 3 in. diam. placed vertically across the flue, leaving segmental spaces on either side; these tubes are expanded in place.

In a Lancashire boiler of ordinary proportions an increase of heating surface of about 70 per cent. over plain flues and about 20 per cent. over Galloway tubes is obtained. Increased evaporation and efficiency as compared with both the above flues are claimed. M.3381.

368. Portion of a collapsed flue of a boiler. Presented by Messrs. Fraser Bros., 1877.

This formed the crown portion of the furnace flue of a Cornish boiler. The flue collapsed under steam pressure owing to the water being allowed to get lower than the crown which became overheated with consequent reduction of strength. The material is best Yorkshire iron and no fracture resulted, so that an explosion was averted.

The flue was built of conical following rings connected by single riveted lap joints, without the stiffening rings, etc., adopted in modern practice. M.1734.

369. Photographs of collapsed flues from a steam boiler. Presented by the Butterley Co., 1898.

These two flues were removed from a cylindrical boiler, the shell of which is 7·5 ft. diam. by 30 ft. in length. The flues were 3 ft. inside diam. by 12 ft. long, made in lengths which were strengthened by Adamson's ring and flanged joint.

The working pressure was 200 lb. per sq. in., but through shortness of water both flues softened sufficiently to collapse as shown, without, however, fracturing or causing any explosion or other damage. M.3033.

370. Corrugated firebox. Lent by Messrs. R. Garrett & Sons, 1894.

The firebox end of a small boiler of the locomotive type is shown. The outer sheet of the firebox has been sectioned to show the construction.

The feature of the firebox, introduced by Messrs. Garrett in 1876, is the means by which the roof is prevented from collapsing under internal pressure. The usual flat roof and girder stays are dispensed with. The crown sheet is corrugated longitudinally and also has a camber in a direction at right angles to the corrugations given to it, thus constituting it a girder of considerable depth and one possessing the desired strength and stiffness. The crown plate was at first made with three corrugations, but in 1879 it was made as shown, a construction which provides a deep water pocket in the hottest part of the furnace. It is claimed that the durability of the firebox is increased owing to the freedom for expansion permitted by this system of construction.

The flat sides are supported as is usual by screwed and riveted stays. The modern method of construction in which, to obviate the use of angle irons and their attendant riveting, the plates are flanged over while hot is shown. M.2724.

371. Drawing of sectional steam boiler. (Scale 1 : 15; details 1 : 2.) Lent by J. Harrison, Esq., 1862.

This steam generator was patented in 1859 by Mr. Joseph Harrison of Philadelphia. It consists of a large number of communicating globular iron

chambers, cast in sets of four; the ends of each set are machined so that tight joints can be made when several sets are held together by internal tie-rods. In this way the cells are connected into slabs, while by suitable castings and tie-rods a number of these slabs are similarly united to form a complete boiler of the requisite heating surface. The slabs are arranged with a slope of 25 deg. in a brickwork chamber, the furnace being at the lower end and the steam pipe at the top, while suitable bridges distribute the gases between the nests of cells. About one-third of the cell capacity is used as steam space, and in it a certain degree of drying or superheating is effected.

Exceptional portability and adaptability were claimed for the arrangement, as well as great safety, owing to the smallness of the individual elements of which the generator is built up. The boiler has since been somewhat modified, and as now constructed is given a slope of 40 deg. with the horizontal. On trial it was found that one of these generators, when tested to 875 lb. steam pressure, leaked considerably at the joints, but that it became tight again upon the pressure dropping to 450 lb. In some forms of sectional tubulous boilers the use of internal tie-rods has given trouble owing to the expansion of the external tube being greater than that of the rod. M.906.

372. Model of water-tube boiler, stoker, and superheater. (Scale 1 : 8.) Presented by Messrs. Babcock & Wilcox, 1903 and 1912. Plate VII., No. 4.

This construction of water-tube steam generator was first patented and introduced in the U.S.A. in 1867 by Mr. S. Wilcox and Mr. G. H. Babcock, and has since undergone considerable modification and development.

The boiler now consists of groups of straight water-tubes arranged over the grate and inclining downwards at 15 deg. into the chamber or flue beyond. The upper ends of these tubes open into special vertical tubes or "headers," connected above to a horizontal drum in which the steam and water rising from the tubes separate; the space within the drum above the water level acts also as the chamber or dome from which the steam is drawn off. The lower ends of the water tubes are similarly connected to the other end of the drum, while the lower ends of these rear headers communicate with a small transverse drum serving as a mud chamber. These downcomers and headers allow water from the separating drum to descend to the lower ends of the tubes, to replace the water carried up as steam, or with it, thus maintaining complete circulation; the solid impurities to a large extent precipitate in the mud-drum, during the downward passage of the water through the rear headers.

The model represents a boiler having 49 inclined water-tubes, 4 in. diam. and 14 ft. long, made of wrought mild steel. They are expanded at each end into the headers, also of wrought mild steel, each containing one zigzag row of tubes to accommodate which the sides of the headers are sinuous. For cleaning purposes these headers are provided with handholes opposite each water tube, the handhole covers being faced metal to metal, and secured by wrought steel clamps. The tops of the headers are attached to the steam and water drum, 4 ft. diam., which is butt-jointed and double-riveted, by means of tubes also 4 in. diam., expanded into holes bored in pressed "saddle-pieces" riveted to the drum; the front tubes are short, but the rear ones much longer on account of the inclination of the main tubes. The mud drum is made of cast metal, or of wrought mild steel, and is connected to the rear headers by short expanded tubes.

STOKER.

Firing is done by hand on a fixed grate or by an automatic stoker. The one shown is of the chain grate type embodying several improvements made by the firm. The travelling chains are formed of links supported on rollers and actuated by sprocket wheels, worm gearing and ratchets from an eccentric on an overhead shaft. The sprockets are adjustable in a frame mounted on wheels and running in channels so that it can be drawn back bodily from the furnace. The hopper is independent, being secured to the

furnace front. It is fitted with a sliding door to regulate the depth of fuel carried on the grate. There is a flap which can be hooked back when it is desired to stoke by hand. At the far end of the grate is an ash plate with renewable nose, and beyond it a dumping door worked by worm and quadrant.

The entire boiler, with the front plates is suspended, so that it can expand or contract without any strain being thrown on the surrounding brickwork, by wrought iron slings from rolled joints resting on iron columns. Two fire-brick baffles arranged among the tubes cause the hot gases from the furnace, under the influence of the chimney draught, to take a sinuous course which, together with the zigzag arrangement of the tubes, ensures a large amount of direct impact by the gases.

The damper is placed in the rear wall, and the doors for cleaning the tubes and removing the soot are in the side walls, while the front is rendered accessible by two iron doors. The boiler is fitted with the usual mountings, comprising main steam stop-valve, safety-valve, feed-valve, blow-off valve, water gauges, and steam pressure gauge.

The boiler represented contains about 900 sq. ft. of heating surface, which would be capable of evaporating from 3,000 to 3,500 lb. of water per hour; such boilers can be constructed for any pressure not exceeding 500 lb. per sq. in.; about 200 lb. is, however, the most usual.

SUPERHEATER.

The model shows also the Babcock and Wilcox steam superheater as arranged in such a boiler, to heat the steam generated beyond the boiler temperature, and so reduce the subsequent losses in the steam engine. This superheater is placed in the space between the drum and the inclined tubes and consists of 4 groups of 6 solid drawn steel tubes 1·5 in. diam. bent into U form, arranged horizontally, and expanded at their ends into two wrought steel boxes or "manifolds," provided opposite the tubes with inspection handholes. The steam from the boiler drum passes down from a collecting pipe into the upper manifold, then through the superheater tubes into the lower manifold, from each end of which it passes by pipes leading to the stop-valve.

To prevent injury to the superheater tubes when steam is being raised from a cold boiler, an arrangement is provided for flooding them with water. This consists of a connection with the water space of the boiler drum and two cocks, by opening the larger of which the water is admitted to the superheater but any steam formed rises directly to the boiler drum. When steam has been got up, before opening the boiler to the steam main, the large cock is closed and the small one is opened, so that the water in the superheater drains away, a gauge glass being provided to show that the draining is completed.

The chimney represented is 30 in. diam., by 60 ft. high, and is composed of wrought iron plates 0·2 in. thick, riveted together; it is secured to a bolted down cast iron base and is stayed by steel wire guy ropes. M.2265 & 4094.

373. Models of Stirling boiler. (Scale 1 : 12.) Lent by the Stirling Boiler Co., Ltd., 1903. Plate VII., No. 5.

This type of water-tube boiler was patented in 1889 by Mr. A. Stirling, and the models show a complete boiler and one in section.

The boiler consists of a number of groups of steeply-inclined tubes, expanded at their upper ends into three cylindrical steam and water chambers, and at their lower ends into two cylindrical mud drums, in which the water, being comparatively quiet, deposits its sediment. The feed water is admitted to the upper chamber farthest removed from the fire, and this chamber contains the automatic float for regulating the water level. The tubes leading thence to the mud drum serve as downcomers for the water passing to other sections of the boiler and, in heating the feed water, act somewhat like those

of an economiser. The sides, roof, and furnace of the boiler are of brickwork, but the weight of the boiler is carried, and the walls supported, by a steel framing. There is a brick arch above the furnace, which assists in directing the flames towards the tubes, and between the groups of tubes are baffles, formed of fireclay slabs, arranged so as to cause the hot gases to traverse the whole of the tube surface before reaching the chimney through the damper door at the back. Through the side wall there are protected openings which give access for the scraping tools used in cleaning the exterior of the tubes. The steam generated is withdrawn from a steam dome fixed upon the central chamber, into which the steam from the wing chambers is led by curved horizontal pipes, an arrangement which, it is stated, conduces to dryness in the steam.

The complete boiler represented is of the middle size constructed, and has 56 sq. ft. of grate area, 2,900 sq. ft. of heating surface, and would supply about 12,000 lb. of steam per hour at a pressure of 160 lb., giving about 600 h.p. with a suitable engine. M.3272.

374. Model of Niclausse boiler. (Scale 1 : 10.) Received 1902.

In this class of water-tube boiler the heating surface is formed by tubes closed at one end and opening at the other into square vertical water chambers, or "headers," while within each tube is a smaller one conveying cooler water from another chamber in the header to the closed end—each double tube acting similarly to the tubes introduced by Mr. E. Field in 1862. The application of the internal circulating tube to the inclined tubes of boilers of the water-tube type was accomplished by M. Collet, who also introduced the double-chambered header; for the attachment of the outer tubes he, however, employed long internal bolts, and these proved to be unsatisfactory. The practical success of the arrangement is, therefore, due to the work of M. M. Niclausse, who invented and patented, between 1891 and 1900, a form of joint for this purpose which has overcome the difficulties and led to the successful introduction of this system of construction (*see also* Marine Engineering Collection).

The model shows, partly in section, a Niclausse boiler having a brick setting. The boiler consists of groups of slightly inclined tubes, closed at the back ends and connected at the front in double vertical rows of headers, which themselves open at the top into a collecting drum or chamber—each double row with its header forming an "element." Within each tube is a smaller one, opening into an outer portion of its header, which also communicates with the collecting drum, so that water from the drum may pass down the headers and through the central tubes to the end of the larger tubes, and then, together with the steam generated, return through the passage between the two tubes and up the headers again into the drum, without the two streams mixing or interfering. The water level is above the bottom of the drum, and a dividing plate separates the hotter water from the cooler portion, including the feed water. There is, however, no lower water chamber, so that this form of boiler cannot be completely emptied without removing the tubes.

The method of attaching the tubes to the headers consists in the employment of a special sleeve or "lantern," passing through the header and fitting it by means of coned surfaces, while the smaller end is screwed to receive the outer tube. The lantern of the inner tube screws into the outer lantern, and dogs outside the headers keep the conical surfaces in contact, little retaining pressure being, however, required owing to the areas nearly balancing. An attached drawing shows this tube joint in detail, and also a later form of greater simplicity.

The boiler represented has a grate area of 45·7 sq. ft., and 1,420 sq. ft. of heating surface; it would supply about 8,800 lb. of steam per hour at a pressure of 256 lb. per sq. in., which, in a suitable engine, would give about 440 h.p. M.3261.

375. Flash boiler. Received 1911.

This form of steam generator, although invented many years ago, did not come into extensive use until it was taken up by Léon Serpollet in 1887, subsequently improved by him, and applied to steam carriages. In it superheated steam is instantaneously generated from small quantities of water pumped into heated tubes, regulation being effected by varying the quantity of water injected according to the demand for steam. The boiler is peculiarly suitable for motor cars, as it can be made very small for a given power, and generates steam at high pressure without being liable to danger from explosion.

The example shown, which is from a steam car of 4·5 h.p., consists of a number of rectangular grids or coils of thick weldless steel tubing, placed horizontally, one above the other, in an asbestos lined sheet steel casing; the coils are joined in series by external coupling pipes. The water enters at the lower end, and the steam generated passes through all the coils, and out at the top to a throttle valve fitted with a pressure gauge. A paraffin burner is fitted, and this consists of a frame of tubing from which eight small nozzles project upward; a steel chimney is mounted above each nozzle, and the fuel is vaporised on its way to the nozzles by passing through a coil of tubing placed above the burner. The burner is started by burning some methylated spirit in a tray below it. The throttle valve is a conical disc pierced with two holes, and fitted on a conical seat through which two similar holes are drilled; a spindle attached to the valve, and passing through a stuffing box, rotates it so as to make the holes coincide and allow the steam to pass. M.3908.

376. Original geyser. Lent by the Parkinson Stove Co., Ltd., 1913.

This apparatus for heating water very quickly for bath, etc., use was patented in 1868 by Mr. B. W. Maughan. The method employed is the subdivision of the water into films on metallic surfaces directly heated by gas flames.

At the top of the apparatus is a covered tank supplied with cold water. A number of nipples are screwed into the bottom, and below each is a helix of wire for the water to trickle over. The drops are caught on an inverted funnel, the outlet of which is shielded, and they collect between it and the outer shell, in which are connections for drawing off the hot water. The burner, which is in the form of a grid or double comb with very fine holes for the gas jets, is inside the funnel. The products of combustion escape through an annular space between the water tank and the shell. There is a burner lighting device incorporated with the main gas cock. Inv. 1913–77.

377. Hot water apparatus. Lent by The Davis Gas Stove Co., Ltd., 1912.

This shows in section a gas-heated, automatically controlled, domestic hot water apparatus.

The important part is the means employed for conducting heat to the water, for which great efficiency is claimed. It consists of a tube, built up, as patented in 1904 by Mr. W. J. Still, of alternate mild steel diaphragms and rings welded together to give a tube gilled internally as well as externally. The tube is enclosed by and in communication with a cast iron water-jacket, on which is the outlet pipe. The inlet pipe is screwed into a box enclosing a thermostat, as patented in 1911 by Mr. H. N. Davis and Mr. W. R. Twigg. It consists of a tube containing oil, sealed by a thin capsule which projects into the gas space. Its expansion, multiplied in the ratio 9 : 1 by a bellcrank lever, acts on a sleeve valve which cuts off the gas to the bunsen burners, although sufficient gas is allowed to flow through a by-pass to keep up a desired temperature; this is usually 70 deg. C., as above that temperature

incrustation is liable to be formed. On its way to the thermostat the gas passes through a plug cock with which is incorporated a device for supplying a pilot light burning with a luminous flame. Access to the water spaces can be obtained without disconnecting gas or water fittings.

These circulators are tested to 60 lb. per sq. in. working pressure; the size shown is suitable for a tank of 25 gal. capacity. M.4047.

378. Drawings of thermal storage arrangements. Presented by Druitt Halpin, Esq., 1902.

The beneficial action of a large volume of water in a steam boiler, in moderating the fluctuations in steam pressure consequent upon variations in the work being done, has long been known, while the practicability of running locomotives for moderate distances solely with the steam obtainable from a reservoir of highly heated water has been repeatedly demonstrated on tramways and in mines.

The thermal storage system employed by Mr. Halpin, while depending upon the same principles as these earlier arrangements, forms a somewhat different application. In the method he patented in 1891–2, which was primarily designed to overcome the difficulties experienced in electric light stations through the great variations in the work required from the plant at various times, the excess of heat received by the boilers when the engine demand for steam is slight is stored in a reservoir of hot water, suitably lagged with non-conducting covering. The reservoir is a vertical cylindrical vessel 30 ft. high by 8 ft. diam., greater capacity when necessary being secured by increasing the number of such vessels.

The boiler and reservoir pressures are higher than that at which the steam is supplied to the engine, and the thermal storage is represented by the difference in the amount of heat in the reservoir at the temperatures corresponding with the higher and lower pressures respectively. With pressures of 250 lb. and 115 lb. absolute it is estimated that each pound of water originally in the reservoir will supply 0·07 lb. of steam at the lower pressure, which steam is thus available to assist the boilers at the time when the demand exceeds their supplying capacity; furthermore, water from the reservoir can be directly admitted to the boilers so that the feed can at the same time be shut off.

When, moreover, through steam having been withdrawn, the temperature and pressure of the reservoir have fallen, the mass of cooler water it contains is capable of condensing steam from the boiler and thereby storing heat when, through a reduction in the demand, the boilers are supplying more steam than is being required.

These lithographs, however, show a modification of the apparatus patented by Mr. Halpin in 1901, in which a storage reservoir or drum is placed on the top of a horizontal boiler and connected with its shell by a tube of large area which extends nearly to the top of the drum, both vessels being at the same pressure. The feed water, from an injector or pump, is introduced at the top of the drum wherein, as it becomes heated nearly to the steam pressure, it deposits its sediment, thus saving incrustation in the boiler itself. This hot water, taken from above the sediment level, is afterwards allowed to flow into the boiler as feed when an exceptional load comes on, the injector feed being at the same time shut off so as to increase the steaming power. By placing one connection within another only one opening in the boiler and reservoir are required. M.3246.

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379. Models of boiler explosions. (Scales as shown.) Presented by E. B. Marten, Esq., 1900.

These models were made by Mr. W. Winship, and formed part of an extensive series commenced in 1862 by Mr. Marten, of the Midland Steam Boiler Insurance Co., to represent the features of the most important boiler

explosions as they were investigated. Amongst them will be found some types of boiler and setting not otherwise represented in the Museum.

Each model is in duplicate, one showing the original state of the boiler and the other the portions of the boiler after the explosion; the two models are, however, placed close together, as considerations of space prevent the distribution of the fragments in the way that actually occurred, some pieces having been hurled more than 300 yd. from their original positions.

The flight of an exploded boiler is due to similar unbalanced forces to those in a rocket, the steam in the boiler and that given off by the water acting like the powder gases. In several of the instances shown, however, the boiler appears to have failed like a rocket case that breaks up as an explosive shell—an action that has not yet been fully explained. The destructive energy of a boiler depends upon the pressure and the amount of water in it, but the damage done by the explosion is largely influenced by the rapidity of the dissipation of the energy as determined by the area of the rent, so that if this is sufficiently restricted the result may be nothing more serious than a leakage of steam or water. M.3132.

BOILER FITTINGS AND ACCESSORIES.

In the working of a steam generator much labour and anxiety are saved by suitable arrangements of the stokehold or boiler room, and by the addition of appliances which automatically perform some of the duties that originally fell to the attendant, while, above all, the disastrous results following any temporary or accidental neglect are, by suitable fittings, together with careful examination at frequent intervals, rendered almost impossible.

Furnaces and details.—Fire-grates consist of an arrangement of bars of cast or wrought iron. Considerable efforts have been made to improve the combustion by increasing the number of and diminishing the spaces between the fire bars, so as to give more diffused and finer currents of air. The supply of air under pressure, and the heating of the same by the otherwise waste heat, are devices successfully adopted for increasing the efficiency of the furnace, but these refinements have been chiefly confined to boilers for steamships in which fuel economy is of the highest importance.

Mechanical Stokers.—These self-acting stoking appliances are being used to an increasing extent, as they save much labour and give more uniform firing than is usually secured by manual labour; they have the additional advantage of preventing the rush of cold air through the furnace, which otherwise takes place when the fire door is open. Their use, is at present chiefly confined to land work.

Water Gauges.—For very many years the only means of determining the level of the water within a boiler was by means of gauge cocks fitted at different heights on the boiler front, the attendant learning the level by testing whether steam or water issued from certain of them. Gauge glasses are now universal, but with the increased pressures frequently used the danger resulting from a burst glass has led to the use of protecting screens of wire or thick glass. In some cases mica is used for the gauge itself; self-closing ball valves are also added to prevent the rush of steam and water continuing after a glass has failed.

The water level in a boiler is usually controlled by an attendant, who turns on the feed when the glass shows it to be necessary and attempts to adjust the feed to the rate of evaporation, but it is becoming general to fit automatic feed regulators. In most water-tube boilers these are especially necessary, as the amount of water contained is small, and its level is not always indicated correctly by the height of water in the gauge glass. These regulators usually consist of a hollow metal float controlling an equilibrium valve in the feed pipe, or a balanced stone float may be used in the same way, but this is generally applied to blow a whistle or ease a safety valve when the water becomes dangerously low.

Fusible Plugs.—The insertion of a lead rivet was early adopted as a means of reducing the risk of collapse should the water get so low as to expose the crown of the furnace; in the more modern application of the device, arrangements are made for ensuring the complete release of the plug in the case of overheating, and also for the replacement of a plug that has been in use so long as to require renewal.

Safety Valves, etc.—The importance of some means of limiting the pressure within a boiler, so that an explosion shall not follow an irregularity in the supply of steam, was practically learned with the introduction of Savery's engine, with the result that in 1707 Papin introduced a form of lever-weighted safety valve. When the boiler is not stationary the weight is replaced by a spring, and in all types it is now general to dispense with the lever, the valve being directly loaded by weights or powerful springs; as an additional security it is usual to fit two safety valves, one of which is frequently "locked-up" so that its load cannot be altered without due authority.

Feed-Water Heaters.—The feed-water of a boiler is sometimes heated in a series of tubes placed in the flue so as to recover the waste heat that was being carried off by the gases to the chimney. In addition to the saving of heat which they effect, feed-water heaters are useful in that much of the mineral matter in the feed-water is deposited in them, instead of in the boiler, where its presence is more objectionable and its removal more difficult. When the engine is non-condensing the use of a feed-water heater, through which the exhaust steam passes, results in a considerable saving of fuel, and it is difficult to understand why so many high-pressure engines are still working without some such useful economiser. The term "economiser" has, however, been appropriated by a form of feed-water heater which abstracts waste heat from the furnace gases after they have left the boiler flues, and it is therefore useful for both condensing and non-condensing engines.

Steam Separators and Traps.—Where a large amount of steam is required from a small boiler the ebullition is so violent that particles of water are carried away by the steam, and if this occurs to an excessive extent great damage may be done to the engine in addition to the waste of fuel resulting from the use of wet steam. The steam dome is one of the earliest and best arrangements for preventing excessive priming, but a large collecting pipe, perforated along the upper surface and extending along the top of the steam space, is a device frequently adopted with long stationary boilers. Where wet steam is unavoidable, or the steam is travelling through a long length of pipe the water particles distributed through it are separated by a drier, in which the steam is usually projected against some surface to which the particles of water adhere and slide down to a receptacle from which the accumulated water escapes by an automatic valve, or trap, to the feed tank.

Furnaces and Details.

380. Boiler furnace door and drawing. Lent by Messrs. W. A. Martin & Co., 1888.

This is a form of door for a boiler furnace, patented by Mr. W. A. Martin in 1867. It is hinged at the top, and balanced so that it will stand at any angle at which it may be placed. When it is opened for stoking the fire, it is turned up, so as to stand full open, opening outward; but when it is desired to admit air above the grate, to prevent smoke after putting on fresh coal, the door can be set open a little way opening inward, in which position its curved surface acts as a deflector, driving the inflowing air down upon the "dead-plate" in front of the grate, so that it shall impinge upon the fuel. M.1936.

381. Model of Perret's furnace. (Scale 1 : 8.) Made by Messrs. Bryan Donkin & Co., 1892.

This shows a boiler furnace for utilising dust or refuse fuel by the assistance of forced draught. It was patented by M. Perret in 1881.

The fire bars are made very deep, and their lower edges dip into a water trough below, by which means the bars are kept comparatively cool. An outside cistern with a ball-cock automatically maintains the height of water in the trough, and a small box outside the furnace has a testing hole at the top through which the height of the water can be ascertained. The forced blast, which is regulated by a throttle valve, is supplied to the closed ashpit at a pressure of 0·5 in. to 1 in. of water, and passes upward through the fuel. The cooling of the bars prevents the adherence of clinker, and their lower outline avoids the trouble that would otherwise result in casting owing to the varying section. M.2439.

382. Furnace fire bar. (Scales, full size and 1 : 3.) Lent by Messrs. N. Varty & Sons, 1900.

This construction of grate bar was patented in 1895 by Messrs. F. and T. Varty and H. Robinson as a means of improving the combustion in furnaces. From the sides of each bar project curved fins, to convert the horizontal motion of the entering air into a vertical one, while at the same time heating it. The fins of the adjacent bars break joint, so as to give a well-distributed draught, while along the centre of each bar is a ledge which facilitates the removal of clinker. M.3134.

383. Furnace fire bars. Presented by the Crosthwaite Fire Bar Syndicate, Ltd., 1910.

These fire bars are of the form patented in 1900 by Messrs. T. Westerby and W. G. Crosthwaite for forced or induced draught.

The bars are perforated transversely, the holes having spigots on one face and faucets on the other so as to make joint when placed side by side in the furnace. Alternate spigots are interrupted to allow air to pass upwards through a recess tapering in two directions so as to form with the adjacent bar a narrow slit on the top surface. The remaining holes communicate with a hollow bridge. The bars have feet which rest on the flues. Two examples are shown, (*a*) for a stationary boiler, forced draught, and (*b*) for a locomotive

boiler, induced draught; the latter has only one set of holes. It is claimed that these bars will burn small coal, etc., remain cool and not clinker, thus giving considerable economy in fuel. M.3777.

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384. Model of Horsfall's refuse destructor. (Scale 1 : 12.) Lent by the Horsfall Destructor Co., 1901.

This arrangement of furnace for the destruction of refuse was patented by Mr. W. Horsfall in 1887–98, and has been extensively adopted. Although such furnaces, when originally introduced in 1876, were only intended to dispose of the ash-bin refuse of towns in an economical and inoffensive manner, it was discovered subsequently that the heat developed during the combustion could be utilised for the generation of steam in boilers arranged about the flues of the destructor; this steam has been very generally utilised in engines employed in electric lighting. The result of working in this way is that the refuse is reduced about two-thirds in weight, to an inoffensive clinker which can be usefully employed, while the excess heat of the combustion generates in the attached boiler about one pound of steam for each pound of refuse consumed.

The furnace of the destructor shown in the model is a low arched chamber built in ganister brick and has more than half of its floor formed of furnace bars, the remaining portion serving as a dead plate. The refuse is introduced on to this dead plate, or desiccating hearth, by a charging door at the back, and the clinker is removed through a wide door at the front. After drying, the charge is burnt upon the bars and the gases all pass over the hottest part of the fire, then upward through a flue, near the clinkering door, into a large combustion chamber, and thence by a downcast flue into the main flue leading to a stack which serves for several of these furnaces or cells. The ash pit is closed, and is supplied, by the action of a steam-jet apparatus, with air under pressure by which the temperature of combustion is raised from 1,000 deg. F. to 1,500 deg., or even 2,000 deg. The sides of the hearth are formed of cast iron boxes which have perforated removable sides, and are cooled by air passing through them on its way to the space below the furnace bars.

The structure is held together and strengthened by steel girders and tie bolts; the various flue-cleaning doors are carried by cast iron frames to which they are hinged, and the large clinkering door slides vertically in guides and is counterbalanced. M.3193.

385. Forced draught furnace. (Scale 1 : 4.) Presented by the Horsfall Destructor Co., 1907.

This shows a furnace, suitable for burning fuel of low calorific value by means of forced draught, provided also with an arrangement for preventing smoke; it is shown fitted to a Cornish boiler, but can be applied to any type.

The grate is made up, according to the nature of the fuel, either of closely spaced bars or of plates of channel section perforated with a large number of conical holes or slots. Each plate or set of bars forms the cover of a trough into which air is forced by a steam jet of adjustable rectangular cross-section. The steam pipe leading to the jets has a pressure gauge, and a stop valve to throttle the steam to the most economical pressure. The small quantity of ash falling through the fine holes into the trough is removed by a rake of special form. Each section being independently controlled, its efficiency is unaffected by the thickness of the fuel elsewhere in the furnace. To prevent smoke, a heated current of air is directed by an independently controlled steam jet above the door down upon the gases rising from the fuel near the bridge.

It is stated that with this furnace upwards of 60 lb. of fuel can be burnt per sq. ft. per hour with greater evaporative efficiency than with natural draught, after allowing for the steam used by the jets. M.3487.

Mechanical Stokers.

386. Model of mechanical stoker. (Scale 1 : 16.) Presented by Messrs. J. S. Smith, Druce & Co., 1908

This illustrates the revolving grate mechanical stoker patented by William Brunton in 1819–20; it was the first successful one of its kind and was somewhat widely adopted. In this instance the apparatus is applied to a brewing copper, set with a wheel draught (*see* No. 349).

The grate is circular and surrounded by a fire-bridge of brick supported in a frame driven at about 1 rev. per min. by gearing from the same vertical shaft which operates the stoker. To prevent access of air except through the fuel, a flange on the under side of the grate frame runs in an annular trough filled with sand. The ashes as they drop are received on an apron attached to this shaft and are swept off by a fixed scraper. There is a door of the usual construction for lighting the fire and clinkering.

The stoker is of the shovel type. Coal from a hopper is admitted in adjustable amount by a slide actuated by a cam on the vertical shaft and returned by a weight. The coal falls on to a shovel which travels on rails; when nearing the grate it tilts on its axis and drops the coal on the grate in a radial position. The to-and-fro motion of the shovel is derived from a cord attached to a lever actuated by a cam and returned by a weight. The periods of rest are timed by the cams. The tilting motion is derived from a guide rail and switch below. The shovel made about 12 strokes per min.; it is boxed in to prevent access of air to the fire. M.3543.

387. Model of travelling furnace grate. (Scale 1 : 8.) Contributed by R. Bodmer, Esq., 1857.

By this arrangement, patented by Mr. J. G. Bodmer in 1834–43, the fuel, while being burnt, is slowly conveyed from the front to the back of the furnace; in this way it is insured that the gases freely given off from the black coal shall pass over the glowing fuel, and so be burnt before entering the flues. One of these grates, 9·5 ft. long by 30 in. wide, was at work in 1843, at Old Ford, near Bow; another, 15 ft. long by 27 in. wide, was used on the Croydon Railway. The work was satisfactory, and smoke was prevented.

The furnace bars are placed transversely, and are carried by two longitudinal screws between whose threads the ends of the bars loosely rest. These screws are continuously rotated by power, and thus move the bars towards the back of the furnace, where they descend and afterwards engage with the threads of two similar screws below, which bring the bars back again to the front of the furnace, where they are automatically elevated to the grate level and again advanced. In the upper screws the threads are cut "drunken" towards the back of the furnace, so that the bars receive a rocking motion which tends to detach any clinker formed, while the lower screws have an irregularity in their pitch which separates the bars so as to allow any cinders that drop to fall between them. Inv. 1857–14.

388. Wall diagrams of Juckes's furnace. Lent by Messrs. Richard Moreland & Son, 1902.

These show an improved form of the mechanical stoker patented in 1841 by Mr. John Juckes, which, although most generally applied to under-fired boilers, has also been successfully used with those of the through furnace flue class and of the water-tube type.

The chief feature of the furnace is that the fire bars are in short lengths and pinned together, so as to form the links of a wide pitch chain which is moved by sprocket wheels at an adjustable rate, by ratchet and reduction gearing from an external source of power. The top surface of this travelling grate is maintained level by a series of transverse carrying rollers, and the sag of the

lower return portion is restricted in the same way, while the wear of the links can be taken up by adjusting screws which move the bearings of the inner sprocket wheels.

The fuel is contained in a hopper at the front, from which it falls on to the in-going portion of the grate, the depth of fuel thus let in being regulated by an adjustable sliding door. The first portion of the furnace is covered by a low firebrick arch which heats the in-going coal and drives off the most volatile gases, so that they shall be consumed by passing over the full length of the fire. The whole grate and its supports are carried on a truck which can be moved in or out on rails when, as in the case of the brewery copper shown, the fire has to be withdrawn upon the completion of a boil while the charge is being drawn off and a fresh one introduced. This class of furnace is practically smokeless, even when using inferior fuel, and it gives a high evaporative efficiency. The furnace represented is for heating a copper 21 ft. diam. and has a grate area of 55·5 sq. ft.; the gases pass round the boiler through flues which give a split draught, and then escape to a chimney, which is shown supported on rolled joists and provided with sliding doors for cleaning purposes. M.3229.

389. Model of mechanical stoker and furnace bars. (Scale 1 : 8.) Lent by Messrs. T. & T. Vicars, 1887.

This construction of machine for feeding the fuel into the furnace and along the grate of a steam boiler was introduced in 1866 by Messrs. Vicars; it has since been extensively used and considerably modified in detail. The general principle of the arrangement is that the coal stored in the hopper above the furnace front is, by the aid of mechanism driven by a small steam engine or from shafting, continually being forced into the furnace front and gradually worked towards the back end of the furnace as the combustion advances; in this way continuous feeding is secured, the undue admission of air while charging is avoided, and the smoke from the "green" coal is compelled to pass over glowing fuel.

The stoker is represented as fitted to the front of a Cornish boiler, the furnace flue of which has been cut to show the arrangement of the grate. The fuel is stored in a large hopper above the stoker, from which it is fed by two inclined rectangular plungers, slowly reciprocated by two eccentrics on a countershaft driven by a ratchet feed from some source of power; the pawl of the ratchet has a projecting pin resting on an adjustable masking wheel, by which the attendant can regulate the supply of fuel to suit the steam demand. These two plungers work alternately and slowly push fuel on to a short perforated dead plate, from which it falls on to the furnace, alternate bars of which are connected with two crossheads reciprocated horizontally by cams on the countershaft. The motion given to the bars is such that, although both sets move backward together, they move forward at different times; in this way the spaces between the bars are freed from clinker, and the mass of fuel is slowly worked towards the further end of the furnace, where the clinker and cinders accumulate and form a bank which acts as a fire-bridge, the excess being removed at intervals by raking it from the ash pit. M.1855.

390. Model of mechanical stoker. (Scale 1 : 12.) Lent by James Proctor, Esq., 1888.

In this mechanical stoker, which was originally patented by Mr. Proctor in 1875, and has since been considerably simplified and improved, the feeding is performed by a flap, which jerks the fuel on to the grate in a way resembling hand-firing with a shovel, the further distribution of the charge being accomplished by the use of reciprocating fire bars.

The model shows the stoker fitted to the front of a Lancashire boiler, and feeding from a single coal hopper above, from which the fuel is distributed by a block, reciprocated horizontally along a pipe, to a small chamber at the front of each furnace. In each of these chambers is a flap which is moved

away from the furnace by pegs on a revolving crank plate and then rapidly swung forward by the action of a spring, thus throwing and distributing the fuel on to the grate in small quantities. The fire bars are arranged in pairs alternately fixed and moving, the latter receiving a slow combined vertical and horizontal movement from a crankpin on a shaft driven by worm gearing. The whole of the motions are derived from a countershaft driven from an engine or by other means. Beneath each automatic feed hopper is a hinged flap for regulating the admission of air, and for use as a fire-door should hand-firing be resorted to. M.1921.

391. Liquid fuel burner. Made by the Great Eastern Railway Co., 1903. Plate VII., No. 6.

Oil as a fuel for steam generators possesses several advantages, the most important of which are that it requires no stoking, is easily conveyed to the furnace, has a high calorific value, and gives a flame that can be immediately and completely adjusted to the demand for steam; it forms no ash, moreover, and consequently exerts no abrasive action upon the firebox and tubes. These advantages were early recognised, and numerous extensive experiments were carried out at various times: in 1834 by Mr. J. Bourne, in the sixties by Messrs. Richardson, Aydon and others, and by Messrs. Sims & Barff, who tried oil fuel on a steam yacht; but it was in Russia, about 1874, that oil fuel first came into extensive use by being successfully applied to locomotives and steamships.

Several methods of burning oil as fuel have been tried, such as mechanical spraying, air or steam jet spraying, and pre-vaporizing, but that introduced in 1865 by Mr. Aydon, in which the oil is sprayed into the firebox by a steam jet drawing in air at the same time, is now most generally used, although for marine work it has the disadvantage of carrying off some of the feed-water.

A conspicuous application in this country of oil for steam raising is that perfected on the Great Eastern Railway by Mr. James Holden, who commenced experimenting in 1886. In his arrangement the oil is sprayed into the firebox by a pair of steam jets, hot or cold air being drawn in through the apparatus at the same time, and additional air introduced by means of a ring steam blower, which also completes the pulverisation of the oil drops. The spray is burnt in the firebox, over a bed of broken firebrick, but an extra brick wall is added where the flame impinges, to prevent undue local heating.

The burners shown, one of which is in section, are the latest form of the arrangement patented by Mr. Holden in 1886–99, for use on a locomotive provided with the vacuum brake. Each burner consists of an outer casing containing three concentric cones forming the nozzles through which pass the air, steam, and oil that form the inflammable spray which is directed into the firebox. As the amount of air thus introduced is insufficient, the spray nozzle is surrounded by a ring of steam jets forming a blower which carries in additional air through the two circular orifices into the firebox, by which the spray is admitted. The central air inlet of these burners is connected with the train pipe, so that the exhaustive action is utilised in maintaining the vacuum, a ball valve preventing the inrush of air when the apparatus is stopped. If the brake service is of the pressure type this economy is not practicable, but a heated air supply is provided by drawing the air through a coil placed in the smokebox. In order to increase the quantity of oil that can be effectually sprayed by the two burners, an auxiliary oil supply is led to the end of the spray nozzles, so that oil from it is carried into the furnace with the mixed jet; the supply of oil to the whole of the jet is, however, regulated by a single combined plug and lift valve.

It is estimated that 1 lb. of oil is practically equivalent in evaporating power to from 1·5 to 2 lb. of coal, and that the most economical oil is the petroleum refuse "astatki," or else coal or oil-gas tar. Similar oil-burning arrangements are used for melting metal in crucible furnaces or on an open hearth. M.3292.

392. Liquid fuel burner. Presented by J. J. Kermode, Esq., 1909.

This is a liquid fuel burner, patented by Mr. Kermode in 1894 and 1898, in which the oil is partially vaporized and sprayed by means of hot air, instead of by steam as in the Holden burner (*see* No. 391). The loss of water in the form of steam is to be avoided in marine work, besides hot air is also claimed to be more efficient than steam. The air is supplied by a compressor, at a pressure varying from 0·5 to 4 lb. per sq. in., according to circumstances, and it is passed through a heater, placed in the furnace or flue, before being led to the burner. The oil is led either from an open tank placed at a height or from a closed pressure tank.

The burner consists of a cylindrical outer casing, made in two parts, and containing two central concentric tubes or sleeves which direct the flow of the oil and air, and also serve as valves. Near the rear end of the casing is a branch for the admission of the fuel and this leads to an axial nozzle which is closed by a conical valve; attached to the valve is a long twisted blade that fits inside the inner tube and serves thoroughly to mix the air and oil vapour, and also operates as a cleaner. The air admission branch is divided. Part of the air is led to an annular space surrounding the oil nozzle which has a conical exterior; the admission annulus may be enlarged or reduced by sliding the bell-mouthed inner tube away from or towards the nozzle by means of a rack and pinion. The remaining air passes between the tubes and the body of the burner, through an annular channel provided with spiral guides, and meets the vaporized oil at the front end of the burner where its exit is controlled by sliding the outer tube by means of another rack and pinion. By this arrangement the heat can be exactly regulated to meet any requirements. No change is required in the construction of the furnace, the fire bars being simply covered with broken firebrick to a depth of from 6 to 8 in.

It is stated that these burners can deal with light or heavy oils, or oil refuse of any kind, and that boilers so fitted can utilise from 78 to 83 per cent. of the calorific value of the fuel used. The example shown is rated at 200 h.p. M.3706.

393. Liquid fuel burner. Lent by Messrs. Clarkson, Ltd., 1909.

This is a sectioned specimen of the liquid fuel burner patented by Mr. T. Clarkson between 1896 and 1904. It consists of a vaporizer, mixing chamber, and burner, with automatic valves to regulate the flame in accordance with the demand for the steam from the boiler which is being fired. The vaporizer is a coil of piping placed in the centre of the flame, and the fuel, which is ordinary paraffin, after passing through this and being vaporized, is led to a nozzle arranged on the axis of an expanding mixing chamber, at the front end of which is placed the burner; air is drawn in at the rear end of this chamber through an adjustable flap valve. The burner consists of a vertical cylindrical chamber, provided round the upper part with eight slots, through which the mixture flows. This chamber is fitted with a disc valve that moves vertically, and increases or decreases the area of the ports. The flame is directed upwards by a metal cone surrounding it, and by a horizontal baffle plate, which is surmounted by a central support carrying the vaporizing coil. The orifice of the vapour nozzle is rectangular, and is fitted with a wedge-shaped tongue piece, which is moved in or out to vary the size of the orifice in one dimension only. The mixture valve and the vapour nozzle tongue are coupled together, so as to work in unison, and are actuated by rods connected with a spring-controlled piston, which is acted upon by the steam pressure in the boiler. If the pressure rises, owing to decreasing demand, the regulator reduces the size of the flame. The burner may be started by heating up the vaporizer by an external flame produced by methylated spirit. M.3704.

Water Gauges.

394. Water gauge and drawing. Lent by Messrs. Llewellins and James, 1888.

This gauge, for showing the level of water in a steam boiler by means of a glass tube, is of the form patented by Messrs. J. L. Nelson and A. F. Landerhohn in 1885. Instead of the ordinary cocks, it is fitted with valves which automatically close and prevent the escape of steam and water in case of a glass tube breaking.

The gauge consists of two fittings attached to the boiler front and having the glass tube held between them in stuffing boxes. Each fitting has an internal cylindrical chamber in line with the tube, and in each of these is placed a valve which, when seated, closes the passage leading to the tube. The valve has a long spindle passing out of the chamber through a stuffing box and provided with a handle; the spindle carries a piston not quite as large as the chamber, so that normally the steam and water can pass round it, but should the tube break the sudden rush of fluid will act upon the piston and close the valve. A collar on the spindle serves as a valve to keep the valve spindle steam-tight when the valve is open, as it must be left free enough to move easily. The steam pressure holds the valves open, when once opened by hand, if the tube is intact. An overflow valve is fitted to the lower chamber. A sectional drawing shows the construction. M.1882.

395. Water gauge. Lent by Messrs. Dewrance & Co., 1910.

This is a water gauge embodying several improvements in detail, patented by Messrs. J. Dewrance and G. H. Wall between 1888 and 1904.

The gauge glass is held at each end by a special form of asbestos and rubber packing, held in loose glands which are enclosed and tightened up by screwed covers. The glands are prevented from rotating and are clipped to the covers so that they are drawn off when the latter are unscrewed. The three plug cocks, by which communication is established with the steam and water spaces and with the overflow, are asbestos-packed (*see* No. 402), the asbestos being caulked into grooves surrounding the passages; they are so formed that it is impossible for the steam to blow them out. The stems are at the small ends of the cones and pass through stuffing boxes; nuts on the ends draw them tight against the packing.

Automatic valves are provided to prevent the escape of steam and water in case of a tube breaking. The one at the lower end is a simple ball valve which normally leaves a clear passage, but which would be forced up against its seat by a sudden rush of water. The ball can be easily removed through the front plug hole. The upper valve consists of a conical valve, held on its seat by the steam pressure, and having a passage through it leading to an orifice in the side of a cylindrical stem. A bent spring has one end opposite the orifice and is of sufficient strength to resist ordinary blowing through, but if the glass tube breaks the steam pressure would overcome the spring and force it over so as to close the orifice. The valve is lifted out through the top plug hole when cleaning out the upper passage. A protecting screen of plate glass 0·5 in. thick is placed round the tube in order to minimise the danger resulting from a burst. M.3749.

Fusible Plugs.

396. Fusible plugs. Lent by Messrs. Allan, Harrison & Co., 1862.

Fusible plugs have long been used as an additional safety appliance to steam boilers.

This example is in the form of a valve, cottered down. The seating of the valve carries the plug well above the furnace crown, and the valve or cap is drilled with a number of holes, each of which is plugged with a fusible alloy. The cotter permits the valve to be easily replaced when necessary, the plug, however, being inserted from the water side. M.709.

397. Copper cap fusible plugs. Lent by Messrs. W. H. Bailey & Co., 1888.

This plug consists of a socket screwed for fixing to the furnace crown and provided above with a nut. It was patented in 1885 by Sir W. H. Bailey. Fusible metal, in the form of a thick disc, covered above with a thin copper cap, is secured to the socket by the nut as shown in the adjacent drawing. The copper cap is intended to protect the fusible alloy from any chemical action of the water and to insure a sudden and complete release of the plug. M.1886.

398. Fusible plugs. Lent by the National Boiler and General Insurance Co., 1888.

In this construction, patented in 1888 by Mr. H. Hiller, the fusible alloy is used to secure a core into a readily removable plug screwed into a gunmetal seating, which is screwed into the furnace crown. The plug is provided with a bevelled edge similar to that of a valve, so as to ensure a tight joint, and the core is formed with a flange, which protects the fusible metal from the direct action of the fire, and prevents its gradual escape. The exterior of the core and the interior of the plug are grooved so that the core is retained in position against the pressure of the steam by the shearing resistance of the fusible alloy.

A complete plug, fixed in a portion of a furnace crown, together with one in section, are shown; these are renewable from the water side. A similar plug and section show the modification necessary when the plug is made renewable from the furnace side. M.1968–9.

399. Fusible plug. Presented by the Vulcan Boiler and General Insurance Co., Ltd., 1906.

This safety device for the furnaces of internally fired boilers was patented in 1904 by Mr. C. Bullock, and is of the pattern approved by the Vulcan Co.

It consists of a serrated copper cone embedded in an annulus of fusible alloy in a cap screwed into the body of the plug. This alloy is protected from non-conducting incrustation, etc., by a cavity therein, the opening of which is filled by the spherical end of the stem of the cone; this serves also as a conductor of heat. When the alloy is melted the cone is not blown out, but after dropping a short distance is stopped by internal ribs, thus leaving a passage for steam.

The size shown is the largest made and is suitable for Lancashire and large Cornish boilers; it is inserted from the water side of the furnace. A pattern for locomotive boilers, inserted from the fire side, is also made. M.3464.

Safety, Stop and Reducing Valves.

400. Wilson-Klotz safety valve. Lent by John C. Wilson, Esq., 1889.

This safety valve, patented in 1876 by Mr. J. C. Wilson, is so constructed that the full pressure of the steam is exerted on the area of the valve even when blowing off freely. The steam pressure is maintained under the crown of the valve by a central pipe reaching well into the steam space of the boiler, while the escaping steam passes to the lip of the valve in the ordinary way. The spring is enclosed in a metal casing to prevent its being tampered with, and also to shield it from the escaping steam. M.2283.

401. Muffled pop safety valve. Presented by the Crosby Steam Gauge and Valve Co., 1913.

This is a locomotive safety valve of the type patented by Mr. G. H. Crosby between 1875 and 1905. It is so designed that it opens suddenly to its full extent when the boiler pressure exceeds the working pressure, thus giving the freest possible discharge, while it closes down again with a reduction of pressure of about 3 per cent. The valve is fitted with a muffler to quieten the discharge, which it does without causing any back pressure. The name of the valve is derived from the popping sound made by the suddenly released steam.

The valve itself is a spherically edged thick flat disc having two annular flat valve faces; this is held down by a helical spring on two similar seats formed on the valve body. When the valve is closed the steam pressure acts only upon the annulus between the two seats, but when the valve begins to open the escaping steam flows outwards over the larger seat direct to the atmosphere, and over the inner seat to a central well which communicates with the atmosphere through four small passages formed in the body. The spring is strong enough to hold the valve down against the normal pressure on the annulus, but when slightly opened, the extra pressure, due to the reaction of the escaping steam on the additional central area of the valve, compresses the spring further and causes the valve to open fully and to remain open until the pressure has fallen sufficiently. The use of flat seats gives the maximum opening for a given lift. The valve is guided vertically by fitting it within a cylindrical casing that encloses the spring. The muffler consists of a narrow annular cylindrical chamber, the inside of which communicates with the main valve outlet, while its walls are perforated for the escape of the steam. The whole valve is surrounded by a casing, having slits at the top, which is screwed on to the body and is adjustable vertically so as to vary the size of the steam passages from the central well and so regulate the action of the valve. The pressure at which the valve opens can be altered by means of a screwed spindle at the top of the casing, which presses on the top of the spring.

The valve shown is 3 in. diam. and, with a lift of 0·08 in., is capable of discharging at the rate of 9,872 lb. of steam per hour at a pressure of 200 lb. per sq. in. M.4111.

402. Asbestos-packed cocks. Lent by Messrs. J. Dewrance & Co., 1880.

This form of plug cock was patented by Mr. J. Mallinson in 1874–75, and subsequently improved by the makers. Its special feature consists in the introduction of fibrous asbestos packing to secure tightness, it being claimed that cocks so fitted retain their tightness longer, and are less liable to set fast than those of the metal on metal construction.

The plug is of the usual form except that it has less taper, and that the key is fitted to the smaller end. The body of the cock is formed with four longitudinal recesses and a circular recess at each end, all of which are packed with asbestos. Above and below the plug are screwed covers, which act as glands for tightening up the packing as required. Three specimens are shown, one of which has a solid bottom and only one gland. M.2507.

403. Model of centre-pressure stop valve. (Scale about 1 : 4.) Lent by Messrs. J. Hopkinson & Co., Ltd., 1907.

This valve, patented in 1903 by Mr. J. Hopkinson and improved in 1906, was designed to lessen the strains both on the valve and seat, whilst ensuring steam tightness. The example is of the screw-down type, with double mushroom valves, working in opposite directions, and closing on oppositely arranged seats in the same partition. The upper or main valve spindle is attached to

a bridge piece engaging with a hollow screw-threaded sleeve of quick pitch. The upper part of this sleeve has a thread of half the pitch, engaging with a second bridge which is supported by pillars from the valve cover and which is capable of a limited movement between collars. The hand-wheel is fastened to the sleeve, and the spindle of the lower or controlling valve passes up through the sleeve and hand-wheel, the lower end of the sleeve bearing on a collar on the valve spindle. On turning the hand-wheel, the valve being shut, the upper bridge first rises until it reaches the stops; the lower bridge and the valve attached to it also rise, at double the rate during this period, owing to the pitch of the thread in the latter being double that in the former. On continuing the rotation of the hand-wheel, the sleeve screws through the upper bridge and descends, carrying with it the lower valve spindle and opening the controlling valve. At the same time the main valve is rising at the same rate, as a result of the differential motion of the lower bridge and the sleeve. A spring is provided to assist in returning the controlling valve to its seat. With this type of valve it is claimed that scoring action on the faces of both valve and seat, when opening or closing, is avoided. The controlling valve also prevents the flow of steam while the main valve is being opened or closed.

M.3512.

404. Model of "Hopkinson-Ferranti" stop valve. (Scale about 1 : 4.) Lent by Messrs. J. Hopkinson & Co., Ltd., 1907.

In this arrangement of stop valve, which was patented in 1904 by Mr. S. Z. de Ferranti, the size of the valve and the perimeter of leakage are reduced by the use of a valve of considerably less area than that of the piping, the requisite flow being obtained without excessive frictional losses by leading the fluid into the valve by a gradually contracting vein, and then after it has passed the valve the excessive velocity energy is reconverted into pressure energy by the use of a corresponding but longer expanding orifice.

The valve is of the sluice type, in two parts, one of which provides a free passage for the fluid, whilst the other contains two discs between which is a spring pressing them to the working faces to ensure steam tightness. The mechanism operating the valve is of the usual type, and consists of a hand-wheel, which can rotate only, causing a left-handed screw engaging with it and with the sluice spindle, to rise or fall, thus opening or closing the valve passage. Any tendency of the sluice to rotate is prevented by a guide attached to its spindle and sliding between pillars. M.3512.

405. Reducing valve. Lent by Messrs. W. H. Bailey & Co., 1888.

This is a valve, patented by Messrs. J. & J. Greenhalgh in 1862, for maintaining a uniform pressure in a steam pipe, less than that of the source from which the steam is taken.

There are two pistons on a vertical spindle, working in cylinders, and the steam is admitted to the space between them; the lower piston acts as a valve, and has portions cut away from its upper part, so that the steam can pass around the lower edge of its cylinder. A spring bears down on the spindle and can be adjusted by a screw which is locked in position. If the pressure of the steam increases, the valve will rise and reduce the area of the passage through which it flows. M.1947.

406. Mason reducing valve. Presented by the Crosby Steam Gage and Valve Co., 1910.

This is an example of the steam pressure reducing valve patented by the Mason Regulator Co., U.S.A., in 1886. In it the main valve is not operated directly by the steam acting on a diaphragm connected with it, as in the earlier reducing valves, but the diaphragm moves a small regulator that admits high-pressure steam behind a piston which then lifts the valve.

The main valve is a single mushroom valve, with a flat face, held on its seat by a helical spring, and lifted by a differential piston placed below it. The upper side of the piston is in communication with the reduced steam, while the lower side is open to the high-pressure steam through a passage which is controlled by the regulator valve. The regulator is placed above the main valve, and its stem is held by a spring in contact with the diaphragm upon the under side of which the reduced pressure acts. The upper side of the diaphragm is acted upon by a helical spring, the pressure of which can be adjusted to give the desired reduction. When steam is admitted, it passes through the regulator to the lower piston, which raises the valve high enough to give the required pressure at the outlet. Any variation in the pressure, on either side of the valve, disturbs the balance of the parts and causes the valve to open or close, so as to keep the outlet pressure constant.

The valve is intended for maintaining a reduced pressure of from 5 lb. to 50 lb. with initial pressures up to 300 lb. per sq. in., but the initial pressure must be from 10 to 15 lb. higher than the reduced pressure. M.3790.

407. Reducing valve. Presented by Messrs. W. H. Bailey & Co., 1903.

The arrangement of this appliance, for automatically reducing the pressure of steam or other fluid to some lower but constant pressure, was patented in 1896 by Mr. J. M. Foster.

The valve itself is of the double-beat equilibrium type, but, to overcome the difficulties arising from the variation in temperature of the stem connecting the two discs, the face of the upper one is nearly flat, while the lower one has a very acute chamfer. Above the valve box, but cast with it, is a circular dish separated by a flexible metallic diaphragm from a similar dish above it which is open to the atmosphere, while the spindle of the valve extends upward and is attached to a cap in the centre of this diaphragm. Above the top dish two horizontal tie-rods, connected by crossheads, control two helical springs under compression, and these, by short vertical levers, press upon a pair of toggle plates, which thereby exert a downward thrust upon the diaphragm and valve spindle.

The boiler steam enters the space between the two valves, and rushes to the reduced pressure pipe beyond; some, however, passes through a vertical communicating orifice to the under side of the diaphragm, which is thereby thrust upward, and carrying the valve with it reduces the supply of steam, and consequently lowers the pressure below the diaphragm. In this way the valve finds and maintains a position in which the pressure of the reduced steam on the diaphragm balances the effort exerted by the external helical springs. By the introduction of the toggle plates the rise in the reduced pressure, which would result from the increased compression of the springs when the valve is fully opened, is prevented by the alteration that at the same time takes place in the angle of the toggle joint. M.3293.

Feed-water Heaters.

408. Model of fuel economiser. (Scale 1 : 8.) Lent by Messrs. A. Lowcock, Ltd., 1902. Plate VII., No. 7.

The name "economiser" is applied to a type of feed-water heater originally introduced about 1845, in which the water before entering the boiler is caused to take up some of the heat in the waste gases leaving the boiler flues and thus economise fuel. A subsidiary advantage is that more duty can be obtained from the boiler with it than without it and troubles from expansion and contraction are minimised. The apparatus is built into the main flue between the boiler and the chimney.

In the particular case shown in the model the boiler is of the Lancashire type and the apparatus is arranged in a by-pass flue with suitable valves, so that the boiler may be worked with or without it.

The economiser shown embodies improvements patented by Mr. A. Lowcock and Mr. T. Sykes between 1880 and 1894. It is constructed of vertical cast iron pipes whose ends are forced by hydraulic pressure into top and bottom headers; the top headers are provided with a lid or cleaning cover, while the bottom ones have a slope towards the blow-off branch pipe, to which is attached a blow-off valve. Each tube is fitted with scrapers, which are moved slowly up and down to remove the soot which would otherwise accumulate and would seriously detract from the efficiency of the apparatus. The scrapers are worked in balanced groups by chains passing over pulleys actuated by worm gear, the reversals at the end of their travel being effected by a tappet-moved, three bevel wheel clutch, assisted by a rolling weight. The soot scraped off falls into a chamber below the pipes and is removed at intervals through cleaning doors.

The feed-water is forced into the economiser by the feed-pump or injector through the bottom branch pipe at the end furthest from the boiler and leaves by the top branch nearest the boiler, so that the hottest gas meets the hottest water.

The economiser is made in sections of from 4 to 12 pipes in width and of any length to suit the number and capacity of the boilers installed. Each tube has over 10 sq. ft. of heating surface. The feed-water is usually supplied to the economiser at 32 deg. C. (90 deg. F.) and leaves at 120 deg. C. (250 deg. F.) to 150 deg. C. (300 deg. F.). A saving of fuel of as much as 20 per cent. is claimed. An indirect advantage of the use of an economiser is that most of the impurities of the feed-water are deposited in the apparatus, whence they can be blown out daily and thus avoid incrustation in the boiler.

M.3260.

409. "Compactum" feed-water heater. Lent by J. Kirkaldy, Esq., 1887.

This is an apparatus, patented by Mr. Kirkaldy in 1885, for heating the feed-water for a boiler by means of the exhaust steam. It consists of four helical coils of pipe, partly interlocking with one another, through which the water flows, and these are enclosed in a chamber through which the steam passes. The ends of the tubes are secured in holes through the cover plate of the chamber by nuts, and the four at each end are covered by a small box to which one of the external water pipes is attached. The coiled pipe is corrugated longitudinally so as to increase the proportion of heating surface to sectional area and space occupied.

M.1873.

410. Drawing of feed-water heater. Lent by James Atkinson, Esq., 1890.

In this feed-water heater, patented by Mr. J. Atkinson in 1877, the exhaust steam from the engine enters at the steam inlet and passes in a direct unimpeded course through a channel provided for it, which is of a similar sectional area throughout, to the steam outlet, from which the exhaust pipe conducts away the steam not utilised in heating the water.

The channel is open at the top to the lower side of the tube plate. Screwed into the tube plate are a number of vertical tubes, open to the exhaust steam at the bottom, but closed at their upper ends, which are left perfectly free to expand or contract without straining. In each of these heating tubes is a small circulating tube leading from near their upper ends to the channel through which the exhaust steam passes, and the mouths are so arranged that the passing steam causes an induced current out of them, and thus out of the upper ends of the heating tubes, removing the air which they contain, or which may be carried in with the exhaust steam, and causing them to be filled with steam. A small portion of the heating tubes projects into the exhaust steam, and assists in diverting the steam into them.

M.2284.

411. Drawing of feed-water heater. Lent by Messrs. Hawksley, Wild & Co., 1894.

In this form of feed-water heater the water passes up through vertical tubes, and then down similar tubes to the boiler feed-pipe below.

The tubes are enclosed in a vertical cylindrical shell through which the exhaust steam is passed, a vertical baffle plate directing the steam over the surfaces of the tubes. The drawing also shows a modified form, in which the steam passes through the tubes and the water is outside them, but both arrangements leave the tubes free to expand independently of the outside shell. M.2731.

412. Model of feed-water heater. (Scale 1 : 8.) Lent by Messrs. Joseph Wright & Co., 1901.

In this heater, which was patented by Mr. R. Berryman in 1871–6, the exhaust steam from the engine is passed through a group of U-tubes, secured into a V-shaped tube plate which serves also as a diaphragm between the steam inlet and outlet; improvements in detail, including the combination with it of an oil separator, have since been added by the makers.

The upper part of the apparatus is made of boiler plate and surrounds the tubes, but can be lifted off for cleaning them externally; into it the feed-water is introduced, the deposited impurities settling in the V-shaped depression of the tube plate, from whence they are washed out at intervals. Beneath this shell is the middle belt, into which the steam enters on one side and, after passing through the tubes, is condensed into water which collects in the base. The base is divided by a diaphragm, which also supports the tube plate and has openings below through which any remaining steam can pass away; the collected water is discharged by a siphon when it exceeds a certain depth. M.3190.

413. Fresh water condenser. Lent by Messrs. Royles, Ltd., 1902.

This condenser embodies improvements patented by Mr. O. M. Row in 1891, and in the form represented would be used in connection with a boiler or "evaporator," for obtaining fresh water from sea water; with slight modifications, however, the arrangement can be converted into a feed-water heater.

The condenser consists of an outer casing containing a number of vertical tubes, the ends of which are either expanded into a tube plate or made tight by some form of screw joint; the cooling water circulates within the casing, its inlet and outlet being at the side, while the steam or vapour to be condensed passes through the tubes, entering at the top and being discharged as condensed feed or drinking water at the bottom. If the water is required for drinking purposes it is aerated by the pipe shown, the air entering through the hooded orifice and passing into the condenser, where it mixes with, and is partially absorbed by, the distilled water.

The chief feature of this condenser is the form of tube employed, of which a short portion of an actual length is shown. This "Row" tube is indented at intervals along its length, so as to reduce the section at each indentation to a narrow rectangle at right angles to the adjacent ones; in this way the free passage along the tube of the vapour and water, both inside and outside, is checked, and the formation of steady streams avoided, thus increasing the transference of heat by the greater amount of impact contact secured.

M.3257.

414. Model of boiler cleaner. (Scale 1 : 12.) Lent by Messrs. A. Ross, Hotchkiss & Co., 1906.

This is an arrangement in which the circulation of the water in the boiler is usefully employed in order to remove foreign matter. It was patented in

1883 by Mr. J. F. Hotchkiss and in the model it is shown as applied to a Lancashire boiler, but it may be fitted on any tubular boiler. It consists of a cast iron spherical vessel, placed on the top of the boiler, preferably at the back end, and connected with it by two stand-pipes, both being continued internally. The up-flow pipe ends in a horizontal funnel-shaped mouth, which is so placed that its lower edge is not higher than the low-water level of the boiler. The mouth is directed to the front end of the boiler in order to receive the surface currents of hot water flowing towards it. The return pipe is continued through the boiler shell as far below the level of the funnel mouth as the construction of the boiler will permit. From the bottom of the spherical vessel a blow-off pipe is led to a convenient place for discharging. When the boiler is in use a continuous circulation is set up through the spherical vessel, convection causing the hot water to rise in the funnel-mouthed pipe, and, becoming cooled, to pass through the return pipe to the bottom of the boiler. The impurities in the boiler water driven to the water level by ebullition are carried with the ascending water into the external and comparatively quiet vessel on the top where the sediment is precipitated. This deposition is assisted by a vertical diaphragm or baffle inside the sphere and cast with it, which prevents undue agitation of the water. The baffle also, by giving the water a longer course, allows greater time for the sediment to settle. The deposit may then be blown off as often as necessary. An air blow-off cock is provided at the top of the vessel. An incidental advantage claimed for the apparatus is that circulation in the boiler is greatly assisted, a continual stream of hot water being delivered to the bottom of the boiler.

Further improvements in the apparatus were patented by Mr. A. Ross in 1894, one of the chief of which was the provision of a charging orifice in the spherical vessel. Some time would, of necessity, elapse before circulation was set up in this vessel, if it were left to charge itself, but by this addition the time lag is obviated. M.3466.

Steam Separators and Traps.

415. Centrifugal steam separator and drawing. Lent by J. C. R. Okes, Esq., 1888.

This apparatus, patented in 1885 by Messrs. C. V. Boys and H. H. Cunynghame, is for intercepting and separating the water held in suspension in steam from ordinary boilers.

The wet steam enters the separator through an inlet near the top tangentially to the circle and whirls round with great rapidity, throwing the drops of water against the sides, whence they run to the bottom, while the steam passes out through a central outlet at the top. A glass tube or water-gauge may be fixed at the side to show the level of the accumulated water, which may either be run off through the bottom valve at intervals by hand or be drained by a steam trap. An adjacent drawing shows the internal construction of the separator. M.1890–1.

416. Vaughan's steam trap. Received 1886.

This apparatus is one of a class largely used for automatically removing the water formed by the condensation of steam in long lengths of steam pipes, steam jackets, etc., without allowing steam to escape.

The sectioned example shown is a steam trap for a 3 in. pipe, and consists of a cast iron vessel fitted with two deflectors by which the steam and its contained water are thrown into the lower portion of the vessel where the water settles by gravity. From the chamber the water escapes by a pipe, communicating with an automatic valve so constructed that it will allow the water to pass but not the steam. This is accomplished by using a horizontal iron pipe carrying at its end a hand-wheel and a stop-valve, and having within

it a copper pipe which carries the seat of the valve at one end but is rigidly fixed only at the opposite extremity. The valve is slightly withdrawn from its seat so as to let the water escape, but when all the water is exhausted and steam enters the copper pipe the greater expansion of copper (about 50 per cent. more than iron) elongates the internal tube sufficiently to close the valve. After a while the further accumulation of water in the collecting chamber cools the copper tube sufficiently to open the valve again. By opening the valve wide, a complete blow through for scouring purposes can be effected. M.2533.

417. Diagram model of Royle's steam trap. Lent by J. J. Royle, Esq., 1887.

This steam trap is constructed so that the mechanism is outside the steam pipes, and, not being subjected to the steam pressure, can be readily examined. It was patented in 1882 by Mr. J. J. Royle.

The section shown represents a cast iron cistern closed by a cover, and provided with an inlet on one side and a siphon discharge on the other. The inlet is closed by a small valve controlled bya powerful float, so that it can resist the steam pressure. The valve leaks slightly, and so the water drains into the cistern, and thus raises the float. This further opens the valve which then admits more water, and finally a little steam that then forces the accumulated water out of the trap by a siphon pipe. A partition divides the lower portion of the cistern into two parts, and the entering water fills the first portion before reaching the float. A small hole in this portion allows a slight passage of water to take place, and this is useful in lifting the float after blowing through. There is a small dead-weighted air valve on the cover which allows any accumulated air to escape, but an expansion rod closes it if steam attempts to pass. M.1864.

418. McDougall's steam trap. Lent by the Chadderton Iron Works Co., 1888.

This steam trap was patented in 1885 by Messrs. I. S. and J. T. McDougall, and consists of a closed cast iron box containing a counterbalanced firebrick float, which controls a horizontal piston valve arranged in the lower portion of the box, and communicating with a drain pipe. The trap is connected with the lower portion of the steam pipe to be drained, and when the water collected in the box reaches a sufficient depth the float lifts and allows some to escape. An external handle is provided for moving the float lever by hand when desired, for testing, without having to open the trap. The attached sectional drawings show the internal construction.

M.1952.

419. Steam trap. Presented by Messrs. Holden and Brooke, 1896.

This apparatus, known as the "Sirius" trap, consists of a light cast iron box, which contains the valve and seating, together with a Bourdon tube. The valve is connected with the lower portion of a steam pipe to be drained by about 10 ft. of pipe, in which the collected water is cooled to less than 212 deg. F. This water enters the chamber, and flows out through a pipe attached to the other end. The Bourdon tube is of tempered steel and hermetically sealed, but contains a volatile liquid, the pressure of the vapour from which rises very rapidly with increase of temperature, so that the difference in the vapour pressure at 210 deg. F. and at 212 deg. F. is sufficient to give a considerable variation in the span of the tube.

The valve and tube are connected together, and pressed by an external set screw against the reaction of a spring towards the valve seat, so that the adjustment can be accurately made. When cool the valve is fully open, so

that the steam pipe is drained on starting; the valve remains open until steam enters the trap and causes the Bourdon tube to lengthen so as to completely close the valve, which remains closed until the temperature falls below 212 deg. F. Unless the discharge from the trap is to be at a higher level the apparatus is free from internal pressure. M.2944.

420. Steam trap. Presented by Messrs. Geipel and Lange, 1906.

This steam trap, patented in 1893 by Mr. W. Geipel, depends for its action upon the difference in the coefficients of expansion of brass and iron. In the body of the trap are two tubes arranged to form two sides of an isosceles triangle; at the apex is situated the valve, whilst the third side is the distance between the ends of the tubes. These ends are fixed in the body of the trap whilst the apex of the triangle is free to move. One end of a spring-controlled lever presses against the valve spindle, which, together with the valve and its shell, is free to move when caused to do so by the expansion of the tubes. The valve is open when the trap is cool, free communication being then established between the steam inlet pipe (brass) and the water outlet (iron). When in use, steam in the brass pipe causes it to expand more than the iron pipe, and the vertex of the triangle, which is practically the valve and its seat, moves, and closes the valves. This position continues until sufficient water collects in the steam pipe to cool it, when its contraction again opens the valve and the water is automatically blown through. Varying pressures of steam are allowed for, as a pressure sufficiently high to cause large movement of the valve would only press the spindle back and compress the spring. The spring is adjusted by means of nuts to keep the valve closed when in use against the normal steam pressure.

This trap may be used in any position, and may be blown through by hand on depressing the lever. The example shown is the smallest size made and has a discharge capacity of 250 gal. per hour. M.3462.

421. Steam trap. Lent by the United Asbestos Co., Ltd., 1905.

This is an example of an expansion steam trap patented by Mr. J. E. L. Ogden in 1898, and improved in 1904–5. Its action depends on the expansion and contraction of a tube operating the valve through which the condensed water is discharged.

It consists of a tube of brass, or other metal with a high coefficient of expansion, connected at one end with a valve casing, the other end being secured to a flange attached to the steam piping which it is required to drain. Two iron rods are mounted with their inner ends carried in a collar pivoted on the end flange, and with their outer ends carried, one against the valve casing and the other against the shorter arm of a spring-loaded lever. The lever operating against the steam pressure bears against the discharge valve spindle and keeps the valve closed.

When the trap is cold, it is arranged that the valve is open owing to the pressure of the upper iron rod on the shorter arm of the bellcrank lever. Steam then passes freely through the trap, raising the temperature of the brass tube, which, expanding, relieves the pressure of the iron rod on the lever, and allows the spring to shut the valve. Condensed water then collects in the brass tube, and, as its temperature falls, the tube contracts, thus opening the valve, when the same series of operations recurs. The effect of the expansion of the brass tube is magnified, first by the bellcrank lever having unequal arms, and then it is doubled by having a pair of iron rods and making the collar against which they bear pivot about the end flange on knife edges. M.3393.

422. McDougall's dirt separator. Lent by the Chadderton Iron Works Co., 1888.

This is a form of trap for removing from steam any water or solid matter mechanically carried along from the boiler or steam pipes. It consists of a circular vessel, closed with a removable cover, and divided into two chambers by a central diaphragm, which is perforated and covered with a metal gauze screen. The steam enters the vessel tangentially, then passes through the screen and onwards to the engine, the screen intercepting any solid matter, whilst a recess around the screen collects the water and delivers it to a drain pipe. M.1953.

423. Examples of boiler scale. Presented by the Institution of Naval Architects, 1871, and S. J. Rowan, Esq., 1881.

The flat piece of boiler scale was taken from the flue of a Lancashire boiler, where it covered three rivets. It has been ground down and polished so as to show the varying stratification, which results from differences in the feed-water and the infrequency with which the boiler is blown out.

The cylindrical specimens are short sections of horizontal water tubes, and show how the area has been contracted by such mineral deposits. The bad heat-conducting properties of the scale are, however, the chief cause of the injuries which result from its accumulation. M.2519–20.

424. Non-conducting compositions. Presented by Messrs. F. Leroy & Co., and Messrs. A. Haacke & Co., 1887.

These compounds are extensively used for covering cylinders, boilers, and steam pipes, with the object of diminishing the serious loss of heat which takes place when the surfaces are exposed to the atmosphere. The materials employed, in addition to being poor conductors, must be incombustible, and when dry should be hard enough to resist a certain amount of rough usage. They are applied, in the form of paste, to the hot surface to be protected, and, owing to the introduction of a fibrous ingredient, possess sufficient tenacity to remain in a position without additional support; when dry the surface is smoothed down and finally coated with a thick paint, &c., which prevents subsequent softening should water accidentally fall on it.

M.1857 and M.1872.

HEAT ENGINES OTHER THAN STEAM ENGINES.

The changes in the pressure or volume of a mass of air consequent upon its being heated or cooled have been utilised as a means of performing work by the combustion of fuel, in the so-called "caloric" or hot-air engine. The earliest actual motor of this kind was that designed by Sir G. Cayley in 1807, in which the heated air passed directly from the furnace to the cylinder, where it did work while expanding down to atmospheric pressure, and was then finally discharged. Mechanical difficulties, chiefly resulting from the high temperature employed, prevented any extensive adoption of this engine, but a few years ago a modification of the system was followed in an engine which attained considerable success; the modern gas engine also resembles it in certain features.

In 1826 Dr. R. Stirling introduced an air engine in which the heat was distributed by means of a "displacer" which moved the mass of air to and fro between the hot and the cold portions of the apparatus; he also compressed the air before heating it, and in this way made a distinct advance in the economy and compactness of the engine. His design is of additional interest in that it was a practical attempt to construct an engine working similarly to the theoretically perfect heat engine, in which the cycle of operations is closed, the same mass of air being used throughout. Stirling was also the first to apply a "regenerator" to absorb and restore alternately some of the heat of the mass of working fluid, and in this way he greatly improved the practical efficiency of this class of motor.

John Ericsson in 1834 constructed an engine somewhat resembling that of Cayley, while in 1852 he built some large caloric engines and adapted them to the propulsion of ships; but since his time the use of large engines of this class has been abandoned, the modern hot-air motor seldom exceeding 1 h.p. The absolute safety and comparative efficiency of the small engines has rendered them of considerable practical use for domestic purposes and light pumping, while for similar reasons the larger caloric engines have been employed as motors in lighthouses and other isolated situations.

The low maximum temperature permissible in a hot-air engine limits the efficiency and causes the machine to be bulky for the power generated; but by heating the air by exploding within it a gaseous mixture, the internal combustion air engine is arrived at, which, in the form of the gas or oil engine, is being so generally adopted. In the case of gas engines using producer gas or the waste gases from blast furnaces the resemblance to the earliest air engine is perhaps more noticeable than in the smaller ones using gas from the mains.

The earliest internal combustion engine was the gun, while as a means of obtaining mechanical power the explosion of gunpowder was utilised in 1678–89 by Hautefeuille, Huygens, and Papin.

The explosion of inflammable gases was similarly utilised by R. Street in 1794, and in 1823 Samuel Brown introduced his vacuum gas engine, several of which were actually constructed. It was not, however, until 1860 that J. J. E. Lenoir produced the first mechanically successful gas engine, and it worked with a cycle, resembling that of a steam engine (*see* No. 431). It was followed by a similar engine by Pierre Hugon (*see* No. 432), and both were double-acting, but owing to the heavy gas consumption they were of but limited application and were generally superseded by the more economical Otto and Langen engine of 1866 (*see* No. 433).

The greatest improvement in the internal combustion engine was, however, that practically introduced in 1876 by Dr. N. A. Otto when he compressed the explosive mixture in the working cylinder before igniting it, as had been proposed by William Barnett in 1838. By this system a much more diluted mixture can be fired, and this gives a quieter explosion and a more sustained pressure during the working stroke, while as the engine runs at a high speed, the flywheel action is generally sufficient to correct the fluctuations arising from there being but one explosion for four strokes of the piston. This method of working has been adopted in most gas and oil engines, later improvements being in the direction of still higher compression and the substitution of lift for slide valves.

While the Otto cycle engine was being developed, considerable attention was given to producing an engine working on a two-stroke cycle, notably by Clerk, Robson and Atkinson. The form now used was patented by Sir Dugald Clerk in 1881, and while it was unable to compete with the four-stroke cycle in small sizes, it has been successfully adopted in large gas engines, where it has proved almost as efficient as the Otto type. There has been a steady increase in the size and power of gas engines; in the larger examples two or more working cylinders are usually employed so as to secure more uniform driving, while sometimes double-acting cylinders are used for the same reason; these have, moreover, been frequently supplied with some cheap form of gas made by decomposing water by incandescent fuel (*see* No. 441), and in this way gas power plants are now working which compare favourably with the most economical steam installations.

When the vapour of naphtha or petroleum is used in place of gas in the explosive mixture, the motor is known as an oil engine, and the Otto cycle is usually followed. Some of the early gas engines were also run on light oils similar to the modern petrol, two of these being Hock's non-compression engine of 1873, and the Brayton engine of 1876. The introduction of the high speed petrol motor is to a large extent due to Gottlieb Daimler, who in 1884 brought out a light and compact oil engine; this was developed by Messrs. Panhard & Levassor, who in 1895 devised the form which has since been generally adopted. The two-stroke cycle is being adopted to some extent in small petrol motors of the valveless form introduced by J. Day in 1891. Petroleum oils

with a high flash point require special vaporising devices, and the first successful engine capable of using such oils was that invented by Priestman in 1885. In 1890 Messrs. H. Akroyd Stuart and C. R. Binney patented the hot-bulb vaporiser and igniter which was the feature of the Hornsby-Akroyd engine, and which has been extensively adopted. In the same year they patented an engine in which the fuel oil was sprayed into pure air at the end of the compression stroke, a system subsequently independently adopted in the high compression engine introduced by Dr. R. Diesel in 1893. The Diesel engine can utilise crude oils in great variety and is made both in the four-cycle and the two-cycle forms, for the latter of which it is peculiarly suitable. In all internal combustion engines from 30 to 40 per cent. of the heat available is carried away by the means adopted to limit the temperature of the cylinder walls and the working parts, while only some 30 per cent. is converted into useful work.

Many attempts have been made to produce a commercial gas turbine, but so far without success.

Hot-air Engines.

425. Model of hot-air engine. (Scale 1 : 8.) Presented by P. R. Hodge, Esq., 1867.

This engine is of the original type designed by Sir G. Cayley in 1807, in which is employed a closed furnace and two cylinders: a small or cold cylinder, forcing air into and around the furnace, and a larger one into which this heated air is admitted to perform the working strokes, afterwards being discharged into the atmosphere.

The model embodies improvements patented by Mr. H. Messer in 1863–4, and has the hot cylinder and the furnace arranged in a rectangular base with the space between them filled with non-conducting material. The furnace itself is a firebrick chamber with a perforated bottom, closed above by a removable charging door. Air from the atmosphere is, by the cold cylinder, pumped into the casing of the furnace where it is heated, while some of it maintains the combustion of the fuel. The heated air and gases then pass to the hot cylinder, where, on account of their greater volume, they perform much more work than was absorbed in working the air pump, the difference being available power for overcoming the friction of the engine and doing external work. The cylinders are both single-acting, and are connected with opposite cranks on a shaft above. The admission and exhaust valves of the hot cylinder are of the drop type, and are controlled by cams operated by an eccentric on the crankshaft. M.1122.

426. Motion diagram of Buckett's hot-air engine. (Scale 1 : 2.) Made by Messrs. H. & T. C. Batchelor, 1889.

This engine is of the type originally patented in 1807 by Sir George Cayley, but in the form shown was commercially introduced by Mr. Buckett about 1880. The engine has a cold-air cylinder above the crankshaft, and a large hot air cylinder below, while the furnace is on one side enclosed in an air-tight chamber: the fuel when required is supplied through a valve and distributing cone arranged above the furnace and provided with an air lock in which the fuel is stored. The speed is controlled by a governor and slide valve by which the air, pumped from the atmosphere by the upper cylinder, is distributed between the firebox and the ash-pit, thus regulating the rate of

combustion according to the work being done. The supply of heated air and the products of combustion pass from the furnace to the lower cylinder; the former is controlled by a drop valve worked from a cam on the crankshaft, a similar valve controlling the exhaust.

At a trial of a double engine of this type, with cylinders 18 in. and 24 in. diam. by 16 in. stroke, the gross indicated h.p. was 41·2, of which the pump used 21, leaving 20·2 effective h.p., of which 14·4, or 71 per cent., was obtained at the brake. The mean pressures on the pistons were 16·7 and 18·5 lb. per sq. in. respectively, and the coke consumption was 2·54 lb. per brake h.p. M.2272.

427. Bailey's hot-air engine (working). Lent by Messrs. W. H. Bailey & Co., 1894.

This engine is constructed on Stirling's principle, and after Laubereau's patent of 1845. It consists of a long cylinder, formed of a closed steel heater at one end, which is surrounded by a furnace, and at the other end of a larger cylinder, enclosed in a water-jacket, by which this end is kept cool. The cold end is fitted with an air-tight piston, which, through two connecting-rods and a weigh-shaft is coupled to a crank on the flywheel shaft. To another crankpin a second weigh-shaft is coupled, and this is connected with a rod passing through a gland in the piston, and attached to the "displacer." This displacer is a loosely-fitting plunger, which is supported by a roller in the cylinder, and its office is to push the air from the hot end of the cylinder to the cold end, and back again, as required. The only valve is a small one, fixed to the cylinder and opening inward, so that any air lost by leakage is replaced whenever the internal pressure falls below that of the atmosphere.

The same air is worked continuously, being alternately heated and cooled during each revolution of the crankshaft. At the commencement of the outward stroke of the piston the displacer is at the cool end of the cylinder, and the bulk of the air, which is accordingly at the hot end, is being heated, so increasing in pressure and driving the piston outward. This movement rotates the crankshaft, and so moves the displacer towards the hot end, thus causing the hot air to pass to the cool end of the cylinder, where the pressure falls through the reduction of temperature due to the cold water jacket, and the return stroke of the piston then takes place, under the action of the flywheel. The work given off is the difference between that done by the air during the outward stroke of the piston and that done upon it during the inward stroke.

In an engine of this kind, with a cylinder 14·6 in. diam., and a stroke of 6·87 in., when running at 106 rev. per min., the brake h.p. was 1·3, and the maximum internal pressure 15 lb. above atmosphere. The mechanical efficiency was 55 per cent., and the coal used 10 lb. per hour. Such engines are made in sizes ranging from 0·25 to 2·5 h.p. M.2568.

428. Ericsson's caloric engine. Received 1913. Plate VII., No. 8.

This is a hot-air engine of the open cycle type in which air is admitted, compressed, heated and exhausted. It was patented in 1855 by John Ericsson, who had worked on the subject since 1825, had patented his first engine in 1833, and in 1852 had built some very large engines for ship propulsion with cylinders 14 ft. diam. The engine shown was made about 1869, and remained in use 30 years.

A cast iron furnace chamber with grate bars and removable linings projects inside a prolongation of the working cylinder. The products of combustion pass through a lagged jacket surrounding the furnace part of the cylinder before passing away to the flue.

In the cylinder move an outer leather-packed working piston and an inner displacer piston both connected with the crank-shaft by link work which

causes them to move in different phase to one another, and gives them different lengths of stroke. In the inward stroke, cold air is drawn in, through weighted non-return valves in the working piston, into the space between it and the displacer, the exhaust valve being lifted meanwhile by a cam. When the displacer has completed 0·9 of its stroke, but the working piston 0·4 only, the exhaust valve closes, and during the rest of their strokes the air is compressed between the pistons and in the space round the furnace. To ensure the air being thoroughly heated a sheet iron prolongation of the displacer works into the annular space between the chamber and a baffle cylinder. The compression and heating of the air causes the return or working stroke, the pistons undergoing the same phases as before, but in the reverse direction, till at the end of their strokes they are close together, and the air between them has been transferred through an annular non-return valve in the displacer, to the space round the furnace. The speed of the engine is controlled by a centrifugal governor opening a waste valve. To stop the engine the exhaust valve can be opened by hand.

The cylinder is 15 in. diam.; the working piston has a stroke of 6·75 in., and the displacer 11·5 in. The engine is said to have developed 1 h.p.

Inv. 1913–125.

(*See* Bourne—Examples of Steam, Air and Gas Engines, 1878, p. 299.)

429. Model of Rider's hot-air engine. (Scale 1 : 2.) Lent by Messrs. Hayward-Tyler & Co., 1887.

This regenerative hot-air engine was patented by Mr. A. K. Rider in 1871–7. It has two vertical plungers of equal diameter, connected with two overhanging cranks set at right angles on a flywheel shaft. The plungers work within two cylindrical chambers, one chamber being kept cool by a water jacket, and the other being heated from below by a furnace, which, in the model, is replaced by a gas burner. The two chambers are in free communication by a connecting box, which, however, is filled with a number of thin cast iron plates, so that a large expanse of metal surface is presented to any air passing through this box, which is the regenerator. The stroke of the hot plunger is considerably longer than that of the cold one, so that, although the pressures under the plungers are always equal, the volume displaced by the hot plunger is the greater. A constant weight of air is enclosed between the two plungers, but as the crankshaft revolves this air is being passed from one chamber to the other through the regenerator. The arrangement of the cranks is such that during the upward strokes of the plungers more of the air is in the hot chamber, and consequently the common pressure is higher than when the plungers are returning. The difference between the power exerted in the upward strokes and that absorbed by the return strokes gives the useful work. In passing through the regenerator the air from the hot chamber leaves some of its heat, which it absorbs again on its return passage, the same air being passed backward and forward continuously, and its pressure rising and falling with each revolution. To replace any loss through leakage a small air valve opening inward is fitted, and through this air enters if at any portion of the cycle the internal pressure falls below that of the atmosphere. A small pump is connected with the cold plunger to maintain the circulation round the cold chamber, and to do useful pumping work when this is required. Such engines run at about 120 rev. per min., and are used where a small motor is required and skilled attendance is not available, the absence of danger of explosion being a valuable feature. M.1871.

430. Lowne atmospheric engine. Lent by Messrs. Hardy and Padmore, Ltd., 1905.

This engine is of the construction patented by Mr. R. M. Lowne in 1889 and 1897. The motive power is obtained by drawing a flame into a cylinder and then cooling the hot gases so that they contract, form a partial vacuum, and allow the atmospheric pressure to force in the piston.

The engine is provided with a vertical water-jacketed single-acting cylinder, and a trunk piston working through a gland packed with asbestos and having a thin steel band for a rubbing surface. The inner end of the trunk is guided by a ring fitting the cylinder and the outer end by guides on the framing. The flap valve at the top of the cylinder is open during the down stroke of the piston, and the gas or other flame arranged to play around its seating is drawn into the cylinder; it closes before the end of the stroke, allowing the imprisoned gases to burn out and cool down in time for the up, or working stroke. The piston drives a crankshaft, with flywheel and pulleys, by means of a jointed connecting rod, the joint being attached to a radius rod which takes from the cylinder and guides the oblique thrust of the short lower portion of the connecting rod, and also serves to operate the valve. The valve is lifted by a lever on a rocking shaft which is moved by the valve rod through a spring connection, so that the valve is enabled to pause on its seat after closing, and is kept closed by the atmospheric pressure during the up-stroke. When the internal and external pressures balance it again opens. The time of closing the valve, thus changing the speed of the engine, is adjusted by turning a nut on the valve rod. The engine will run equally well in either direction. The water-jacket is connected with a tank and natural circulation is arranged for.

In the engine shown the flame is supplied by a Bunsen gas burner. The cylinder is 2 in. diam. by 4·75 in. stroke and with an average vacuum of 5 lb. per sq. in. is estimated to give about 0·067 brake h.p. At a test one of these engines gave nearly 0·1 h.p. at 480 rev. per min. on a consumption of about 100 cub. ft. of coal gas per brake h.p. hour. M.3387.

Gas and Oil Engines.

431. Lenoir's gas engine. Made by the Reading Ironworks Co. Received 1865. Plate VIII., No. 1.

This engine was patented by Monsieur J. J. E. Lenoir in 1860, and although embodying no features not then already known, was the first practically successful gas engine.

To start the engine, the flywheel is pulled round, thus moving the piston, which draws into the cylinder a mixture of gas and air through about half its stroke; the mixture is then exploded by an electric spark and propels the piston to the end of its stroke, the pressure meanwhile falling, by cooling and expansion, to that of the atmosphere when exhaust takes place. In the return stroke the process is repeated, the action of the engine resembling that of the double acting steam engine, and having a one-stroke cycle. The cylinder and covers are cooled by circulating water. The spark for firing was supplied by two Bunsen batteries and an induction coil, the circuit being completed at the right intervals by contact pieces on an insulating disc on the crankshaft; the ignition sparks leaped across the space between two wires carried 0·15 in. apart in a porcelain holder.

The engine shown is of 0·5 nominal h.p., and was used for two and a half years in this Museum. The cylinder is 5·5 in. diam. by 8·5 in. stroke, and at 110 rev. per min. indicated 1 h.p. Prof. Tresca found that a 1 h.p. engine of this type used 96 cub. ft. of Paris gas per h.p. per hour, at 94 rev. per min., the charge being 7·5 of air to one of gas. M.986.

432. Hugon's gas engine. Made by F. B. Vallance, Esq. Received 1868.

This engine was patented by Monsieur P. Hugon in 1865, but he had then been working at the subject for some years. The only important difference between it and the Lenoir is that the ignition is accomplished by an external flame, instead of by electricity; it was, in fact, the first engine in which ignition by flame was successfully accomplished.

The igniting flame is carried to and fro in a cavity inside a slide valve, moved by a cam so as to get a rapid cut-off, and permanent lights are maintained at the ends of the valve to relight the flame ports after each explosion. The gas was supplied to the cylinder by rubber bellows, worked by an eccentric on the crank shaft, but this arrangement is now imperfect.

This engine has a cylinder 8·2 in. diam. by 10 in. stroke, and was nominally of 0·5 h.p. It worked in this Museum from 1868 to 1880, and at 75 rev. per min. indicated 0·78 h.p., with a mean pressure of 3·9 lb. per sq. in., and a maximum of 25 lb. Prof. Tresca found the gas consumption in a similar example to be 85 cub. ft. per brake h.p. hour. M.1098.

433. Atmospheric gas engine. Presented by W. J. Crossley, Esq., 1897. Plate VIII., No. 2.

The feature of this engine is that it has a "free" piston—an arrangement that was first proposed for a gas engine in 1857, but only brought into a practical form by Herrn E. Langen and N. A. Otto under their patent of 1866. The machine was noisy and limited to small sizes, but the gas consumption, being much less than in any previous form of engine, led to its extensive adoption, so that it is generally considered to be the first commercially successful gas engine. The example shown was the first engine of the kind made in Britain.

The cycle of operations in the engine is as follows:—

(*a*) The piston is lifted about one-tenth of its travel by the momentum of the flywheel, thus drawing in a charge of gas and air.

(*b*) The charge is ignited by flame carried in by a slide valve.

(*c*) Under the impulse of the explosion, the piston shoots upward nearly to the top of the cylinder, the pressure in which falls by expansion to about 4 lb. absolute, while absorbing the energy of the piston.

(*d*) The piston descends by its own weight and the atmospheric pressure, and in so doing causes a roller clutch on a spur wheel gearing with a rack on the piston rod to engage, so that the flywheel shaft shall be driven by the piston; during this down-stroke the pressure increases from 4 lb. absolute to that of the atmosphere, and averages 7 lb. per sq. in. effective throughout the stroke.

(*e*) When the piston is near the bottom of the cylinder, the pressure rises above atmospheric, and the stroke is completed by the weight of the piston and rack, and the products of combustion are expelled.

(*f*) The flywheel now continues running freely till its speed, as determined by a centrifugal governor, falls below a certain limit when a trip gear causes the piston to be lifted the short distance required to recommence the cycle.

Ignition is performed by an external gas jet, near a pocket in the slide valve by which the charge is admitted; this pocket carries flame to the charge, thus igniting it without allowing any escape. The valve also connects the interior of the cylinder with the exhaust pipe, and a valve in the latter controlled by the governor throttles the discharge, and so defers the next stroke until the speed has fallen below normal. To run the engine empty about four explosions per minute are necessary, and at full power 30 to 35 are made, so that about 28 explosions per minute are available for useful work under the control of the governor.

The example shown has a cylinder 6·25 in. diam., and an average stroke of 39 in.; it was rated at 0·5 h.p., and the gas consumption was about 26 cub. ft. per brake h.p. hour. M.1856.

434. Bisschop's gas engine. Lent by Messrs. J. E. H. Andrew & Co., 1888.

This engine was introduced by Monsieur A. de Bisschop about 1870–4, and was extensively used for many years as a small motor of from 1·5 to 4 man power; the example shows the smallest size. It has a single vertical cylinder with a return connecting rod working on to a crank; the crankshaft is,

however, on one side of the axis of the cylinder, so that at the time of the explosion, and when, therefore, exerting its maximum pressure, the connecting rod is nearly vertical and at right angles to the crank. The cylinder is single-acting, and draws in a charge of gas and air during about one-half of its up-stroke, through separate ports, each provided with a non-return valve consisting of a perforated metal cover supporting a sheet of rubber, which is forced away when the pressure within is less than without; the charge is then ignited by an external gas flame sucked into a small side passage, which is opened momentarily. The cylinder is cooled by external gills or radiators, and has no water-jacket. One of these small non-compression engines required about 120 cub. ft. of gas per brake h.p. hour. M.1949.

435. Rotary gas engine. Received 1886.

This form of gas engine was patented by Mr. S. Ford in 1874. The working chamber is a water-jacketed horizontal cylinder, with a crescent-shaped block or abutment secured to it on one side. Concentric with the cylinder is a flywheel shaft, carrying within the chamber a cylindrical drum, the diameter of which is such that the drum touches the abutment. Through the drum is a longitudinal diametral slot, fitted with two blades or pistons, which by an intervening spring, mutually press outwards, but the shape of the abutment was intended to give a constant diameter, while the spring secured an elastic contact. As the shaft revolves, this diametral piston is forced to and fro by the interior surface of the chamber, and with the abutment divides the volume into three portions of continually varying dimensions.

By the revolution of the piston, gas and air are drawn into the chamber through a port at the bottom of the cylinder, and a little later an external flame explodes the mixture, generating a pressure which, acting on the unbalanced area of one blade, causes the flywheel shaft to revolve. After thus doing work, the products of combustion escape through an outlet at the top of the chamber. There are two explosions per revolution, but, in common with all engines of its time, there is no compression of the charge before ignition.

The admission of gas and air to the cylinder is controlled by a semi-rotary plug valve, which also shuts off the intermittent igniting flame, the latter being re-lit after the explosion by a permanent light at the side. This valve is driven by a cam on the flywheel shaft; the exhaust outlet has no valve, but is shut off periodically by the revolving piston.

It is stated that the engine ran at about 100 rev. per min., and gave off 0·3 brake h.p., with a gas consumption about the same as that of the Hugon engine. M.1636.

436. Otto's gas engine. Lent by Messrs. Crossley Bros., 1888. Plate VIII., No. 3.

This is a small example of the first silent high-speed gas engine, and was constructed under the patent obtained by Dr. N. A. Otto in 1876. It works on the "Otto," or four-stroke cycle, now so very largely used in gas engines, by which silent working and a great reduction in the gas consumption are simultaneously effected. Although Dr. Otto was the first to construct and introduce practically an engine working in this way, the scheme had been proposed by Mons. A. Beau de Rochas in a treatise published in 1862, so that this cycle sometimes bears his name.

The engine is single-acting, and when exerting its full power makes one explosion or working stroke in every four strokes; the first outward stroke draws in a cylinder-full of gas and air, which, in the second or return stroke is compressed into the clearance space left at the back of the cylinder; at the commencement of the second out-stroke this compressed charge is fired, the resulting high pressure driving the piston through this third stroke, and by the crank and shaft transmitting much energy to the flywheel. At the

completion of this stroke the exhaust valve is opened, and remains open during the return or fourth stroke, during which the products of combustion are delivered by the exhaust pipe into the atmosphere; the next outward stroke commences a fresh cycle by taking in a new charge. By compressing the charge before firing it, nearly double the amount of air that otherwise would be permissible can be present in the mixture without preventing its being ignited, this additional cushion moderating the violence of the explosion and giving a more sustained pressure during the working stroke.

The cylinder is water-jacketed, and the gas and air are admitted by a slide valve at the back, which serves also as an igniting valve by carrying a pocket of flame from an external light to a small port; the exhaust valve is of the drop type, and is placed at the side of the cylinder. Both valves are actuated by a shaft driven by gearing at one-half the speed of the crankshaft. In later practice slide valves have been displaced by those of the drop type, and the ignition is generally performed by a porcelain tube heated to redness by an external gas jet. The speed of the engine is regulated by a centrifugal governor, which, when the normal speed is exceeded, prevents the admission of gas, so that no explosions take place till the speed has fallen to the prescribed limit.

At the trial by the Society of Arts in 1888, one of these engines, with a cylinder 9·5 in. diam. by 18 in. stroke, ran at 160 rev. per min., and developed 17·5 indicated h.p., of which 14·7 was available on the brake, so that the mechanical efficiency was 86 per cent.; the gas consumption was 24·1 cub. ft. per brake h.p. In 1894, by some improvements and still higher compression, the consumption of gas per brake h.p. had been reduced to 16·5 cub. ft. M.1913.

437. Atkinson's "Differential" gas engine. Lent by the British Gas Engine and Engineering Co., 1888.

This is the original engine patented by Mr. Atkinson in 1885, and exhibited at the Inventions Exhibition. By its action the charge is compressed before ignition, an impulse is obtained every revolution, and expansion is carried out to such an extent that the volume of the discharged gases is about double the initial volume of the charge; also, the waste products are almost completely expelled.

In the single cylinder are two pistons, connected with a common crank-pin by bellcranks and links. At the commencement of the cycle the pistons almost meet, the left-hand one then moves rapidly outwards, drawing in the charge of gas and air, and on reversal compresses it while, owing to the position of the links, the other piston has barely moved. The left-hand piston at the limit of its travel uncovers a port leading to an external hot tube by which the charge is ignited. The crank is now in such a position that the right-hand piston moves rapidly and completes a long stroke, after which the products of combustion are expelled by the two pistons approaching each other till they almost meet. This action may be studied in the attached diagram model (scale 1 : 8). The actual engine shown is of 1 h.p. M.1883.

438. Diagram model of Atkinson's "Cycle" gas engine (working). (Scale 1 : 4.) Made in the Museum, 1894.

This represents an engine introduced by Mr. J. Atkinson in 1886 as an improved machine for obtaining the same action as was secured in his "differential" engine, No. 437.

The engine has one cylinder, and is single acting, but by a peculiar arrangement of links two double strokes are made for one revolution of the flywheel, and as it is a compression engine this gives one impulse per revolution. The connecting rod from the piston is attached to a crank arm, which only vibrates through an angle of 90 deg., while from the pin of this crank another connecting rod passes upward to the crank-pin of the flywheel shaft; this connecting rod is triangular, having three pin joints. The result of this arrangement of mechanism is that the explosion stroke is about twice the length of

the compression one, so that a considerable degree of useful expansion, with corresponding economy, is secured. The cylinder is water-jacketed, and tube ignition is employed.

The engine represented was of 6 h.p., with a cylinder 9·5 in. diam. and a crank throw of 12·87 in., which, running at 131 rev. per min., exerted 9·5 brake h.p., with a gas consumption of 22·6 cub. ft. per brake h.p. hour.

M.2565.

439. Model of "Otto" gas engine. Made by Messrs. G. Cussons, Ltd., 1902.

This is a diagrammatic model illustrating the chief features of an internal combustion engine working on the "Otto," or four-stroke cycle.

The piston is single acting, and in its first out-stroke draws in gas and air through two drop valves worked by a lever from a cam on a shaft running at half the speed of the crankshaft. In the return stroke these mixed gases are compressed into the clearance space left at the end of the cylinder, and at the commencement of the second out-stroke are fired by a red hot tube with which they are then placed in communication. During this "explosion" stroke the piston is being forced outwards under a high but rapidly diminishing pressure, the energy thus transmitted to the crankshaft being chiefly absorbed by the flywheel which subsequently delivers it as driving power during the two revolutions which are included in the cycle.

The speed of the engine is regulated by an inertia governor which completely cuts off the supply of gas when the normal speed is exceeded, so that there is no explosion, and the subsequent two strokes are performed entirely by the energy in the flywheel. This governor is in the form of a spring-controlled weight, hinged to the gas admission lever, and so arranged that if the admission lever is flicked by the cam with more than the normal velocity a tappet attached to the weighted portion fails to engage with the gas admission valve.

The cylinder is enclosed by a jacket through which water is circulated, in order to prevent the working parts from reaching a temperature that would rapidly destroy them; this at present necessary cooling, however, carries off about 30 to 40 per cent. of the available energy generated by the combustion of gas.

K.584.

440. Two-cycle gas engine. Presented by the Day Motor Co., Ltd., 1914.

This is a small experimental valveless engine patented by Messrs. J. Day and F. W. C. Cock in 1891 and 1892. It operates on the two-stroke cycle patented by Sir Dugald Clerk in 1881, but has no valves, the distribution being performed by the passage of the piston over ports formed through the cylinder walls.

The engine has a single vertical cylinder, 2 in. diam. by 3·25 in. stroke, and developed about 1 h.p. The cylinder has a liner forming a water jacket, and the separate head is also jacketed; it is cast in one with a closed crank chamber, one cover of which carries a crank shaft bearing, while a second bearing is mounted on a standard beyond the flywheel. The ascent of the piston causes a partial vacuum to be formed in the crank chamber, and when near the top of its stroke its lower edge uncovers ports which admit the gas and air, in the correct proportion, to the crank chamber. The descent of the piston then compresses the charge to a pressure of a few pounds per sq. in.; when near the bottom of its stroke its upper edge first uncovers the exhaust port and next the inlet port which communicates with the crank chamber, so that the products of combustion are expelled and the fresh charge introduced during a very short period of time. The charge is compressed on the next upstroke and ignited by a hot tube screwed into the cylinder head. A projecting fin on the piston deflects the entering mixture upwards to prevent it from passing directly to the exhaust. This engine was afterwards developed into the well-known Day petrol motor (*see* No. 449).

Inv. 1914—730.

441. Model of suction gas plant. (Scale about 1 : 8.) Lent by the National Gas Engine Co., Ltd., 1910.

The idea of working a gas producer, used in conjunction with a gas engine for power purposes, by means of suction induced by the engine itself, instead of by steam pressure, is due to Mons. Leon Benier of Paris, who designed the first plant of this kind in 1894. It follows that the production of gas is automatic and that the pressure in the plant is below that of the atmosphere, so that danger from gas leakage is absent. Benier provided the engine with a separate pump for suction, but it is now found that, if the generator be not too far from the engine, the suction stroke of the latter is all that is necessary. A suction gas plant costs less, is simpler to work and requires less labour than a pressure plant, but suction gas is of less calorific power than pressure gas.

The plant consists essentially of a generator and a scrubber. The former part has a hopper to feed in the non-bituminous fuel—*i.e.*, charcoal, anthracite or coke—which is used; below this is a fuel-container, whence the fuel falls into a firebrick lined producer provided with a grate and closed ash-pit. Around the fuel-container is an annular space, through which the hot gases pass. Bounding this annular space is a ribbed cast iron vaporizer, of the form patented in 1906 by Messrs. H. N. Bickerton and P. W. Robson. Water is caused to trickle over the exterior of the vaporizer to form steam; thus it works on the flash principle and the steam can be easily regulated—an important factor in working. The vaporizer can easily be scaled, as the surrounding shell is removable. The sensible heat of the outgoing gases is further used in warming the incoming air and feed-water; the former mixes with the steam in the vaporizer and they pass together into the ash-pit. The gas then passes by a pipe with a water seal to a scrubber filled with coke over which a stream of water from a sprinkler pipe and distributing dish is continually trickling. The clean and cool gas finally passes to the engine. When starting the plant, a centrifugal fan, worked by hand, is used for blowing the producer, and the gases generated are allowed to pass with the air by opening the cock on the open vertical pipe.

In tests of suction gas plants made at Derby in 1906 for the Royal Agricultural Society, a 20 brake h.p. "National" plant showed a consumption per brake h.p. per hour of 1·04 lb. anthracite coal and 1·14 gal. of water. For its design and performance it received the highest award—a gold medal.

These plants are made in sizes up to 300 h.p. M.3822.

442. Petroleum engine. Lent by J. H. Knight, Esq., 1891.

In this engine, patented by Mr. Knight in 1887–91, vaporized petroleum instead of gas is used in forming the explosive mixture. The petroleum oil is vaporized in a chamber at the back of the working or combustion cylinder, the temperature maintained by the cylinder being sufficient for this purpose; but when starting cold a special paraffin lamp situated under the chamber is lighted, and in about a quarter of an hour heats the vaporizing chamber to the requisite temperature for starting, when it may be extinguished. This arrangement was adopted in the "Trusty" oil engine.

The engine is single acting and has a cycle of six strokes, two being added for scavenging. The charge is ignited by a wire helix mounted on the slide valve. The helix is maintained white hot by a mineral oil blow-pipe worked from a bellows at the side of the engine, and at the right instant the valve carries the helix from the flame and slides it over a cylinder port, thus placing it in the already compressed explosive charge. The governor acts by regulating the quantity of oil fed into the vaporizing chamber by the small pump which forces it from the reservoir in the engine bed.

The motor shown is of 0·5 h.p., and it is stated that 1 lb. of petroleum consumed in it does the same amount of work as 2 to 2·5 lb. of coal in a steam plant of similar power. M.2373.

443. Diesel engine of 5 h.p. Received 1913.

This is an example of the small four-stroke cycle oil engine designed by Dr. R. Diesel in 1909. It possesses all the features of the larger engines and

works on the system developed from that patented by Dr. Diesel in 1892 and 1895.

Diesel's original idea was to apply the Carnot cycle to practice, but this was found to be impracticable, so that a modification of it was adopted. The cycle consists of four strokes, during the first of which the piston moves outwards and draws air alone into the cylinder through the inlet valve; on the second stroke the piston moves inwards and compresses this air to a pressure of about 500 lb. per sq. in. At the beginning of the third or working stroke the oil fuel is injected into the cylinder, through a special needle valve, by an air blast at a pressure of about 650 lb. per sq. in., and it there burns quietly at constant pressure during the short admission period and expands to the final pressure during the remainder of the stroke. On the fourth stroke the products of combustion are expelled through the exhaust valve. The temperature of the compressed air is so high that no other ignition apparatus is required and almost any kind of crude oil can be completely burned, while even coal dust has been employed. The quantity of air in the cylinder is greater than that required for complete combustion of the fuel injected, in order to prevent the temperature from rising too high.

The engine shown has a single water-jacketed vertical cylinder 100 mm. (3·94 in.) diam. by 140 mm. (5·52 in.) stroke, and develops 5 h.p. when running at 600 r.p.m., on a fuel consumption of 0·53 lb. per brake h.p. per hour. The cylinder has a trunk piston and is bolted to a closed crank chamber forming the engine bed. The three working valves, and the air starting valve, are all fitted in the cylinder head, and are operated, through rocking levers and long tappet rods, by a transverse cam-shaft placed just above the crankshaft. The compressed air for the fuel injection and starting is supplied by an air pump placed beside the working cylinder, and having its piston driven by a crank on the main shaft. The fuel air passes directly to its valve, while that for starting is stored in steel reservoirs fixed beside the engine. The fuel is supplied to the injection valve by a small pump driven from the end of the cam-shaft and the quantity delivered is controlled by a centrifugal governor acting on a by-pass valve. When starting, a cam acting on the starting valve is brought into operation and compressed air is admitted to drive the engine for a few revolutions, when the valve is again put out of action.

The thermal efficiency of the Diesel engine is rather higher than that of the explosion gas engine, and has reached 40 per cent., but the mechanical efficiency being lower reduces the brake thermal efficiency to a maximum of about 32 per cent., which is comparable with that of the gas engine. The mean effective pressure in the cylinder is from 110 to 120 lb. per sq. in., and a fuel consumption, at full load, of slightly over 0·4 lb. per b.h.p. hour has been attained. Inv. 1914–87

444. Diagram model of petrol motor (working). (Scale 1 : 2.) Made in the Museum, 1912.

This model is designed to show the operation of a petrol motor (*see* No. 445) working on the "Otto" or four-stroke cycle. A revolving pointer indicates the function of each stroke and the points in the stroke at which the valves open and close, while another pointer moves over a power diagram such as would be described by an indicator attached to the cylinder.

The four-stroke cycle—so called because there is one working stroke in every four strokes—is used in most of the internal combustion engines of to-day. The efficiency of the cycle depends upon the compression of the gaseous mixture before ignition, which gives a high initial pressure and a large temperature range. External pumps were avoided, and the engine simplified, by making the engine single acting and by using the cylinder alternately as a power cylinder and a pump; a heavy flywheel was provided to store enough energy to perform the pumping stroke.

During the first outward stroke of the cycle the inlet valve opens and the piston draws in a cylinder full of petrol vapour and air; the inlet valve then closes, and in the second or return stroke the mixture is compressed into the clearance space left at the back end of the cylinder. At the commencement

of the second out-stroke the compressed charge is fired by an electric spark, the resulting high pressure driving the piston through this third stroke and storing much energy in the flywheel; near the end of this stroke the exhaust valve opens and remains open during the return or fourth stroke, by which the products of combustion are delivered through the exhaust pipe to the atmosphere. The exhaust valve then closes, and a fresh cycle commences with the next out-stroke.

Petrol motors are now usually governed by throttling the incoming charge, thus reducing the compression and power, but at the same time reducing the efficiency. M.4168.

445. Petrol motor with magneto-electric ignition (working). Made by the Simms Manufacturing Co., Ltd., 1905. Plate VIII., No. 4.

This is a high-speed internal combustion engine working on the Otto four-stroke cycle (*see* No. 444), using petrol as fuel; it is designed for use on motor cars and launches, or for industrial purposes.

The engine has one single-acting cylinder 95 mm. (3·74 in.) diam. by 110 mm. (4·33 in.) stroke, and develops 5 h.p. when running at its normal speed of 1,200 rev. per min. but may develop 6 h.p. when accelerated. The cylinder is cast in one piece with its head, valve chamber, and water jacket. It is mounted vertically over a closed aluminium chamber supporting the crankshaft in bearings at each end, and carrying at one side a cam-shaft driven by toothed wheels, at half the speed of the crankshaft. The elongated piston is packed with three spring rings, and the connecting rod is attached by a pin passing through it. The crankshaft is balanced and carries on one end a heavy flywheel whose coned interior forms one member of a friction clutch through which the power is transmitted. Wings formed on the crank chamber support the engine from a suitable framework. The valve chamber is divided by a horizontal partition in which are formed two seats for the inlet and exhaust valves, the port leading to the cylinder being above it. The valves are of steel, and their spindles extend downward through the bottom of the chamber to meet the cam rods which operate them, springs being provided to return the valves to their seats. Below the valves the chamber is divided vertically, one side being the inlet and the other the exhaust. The valves are easily removed after taking out a screwed plug above them and a cotter in the spindle.

Petroleum spirit or petrol, a mixture of light hydro-carbons obtained by the distillation of crude petroleum and having a sp. gr. of 0·7 to 0·76, is used in preference to the heavier and cheaper oils chiefly on account of its easy vaporization, certainty of ignition, and small residue. The explosive mixture, consisting of 1 vol. of petrol vapour and 17–20 vols. of air, is prepared in a float-feed carburetter of the Daimler-Maybach type. This consists of a chamber attached to the inlet pipe of the engine having in the centre a fine vertical nozzle; the nozzle communicates with a larger chamber containing a float which actuates, by weighted levers, a needle valve so as to keep the petrol at a constant height in the nozzle. During the suction stroke of the piston air is drawn in round the nozzle through adjustable openings and draws off the petrol, which is vaporized and mixed with it in a fairly constant proportion. The petrol enters at the bottom of the float chamber through a gauze strainer. The ignition of the mixture is performed by a low tension spark, the current being supplied by a magneto-electric machine of the form patented by Messrs. R. Bosch and F. R. Simms in 1897–98. This consists of a permanent compound horseshoe magnet fixed vertically on a non-magnetic bed-plate and having an armature of H section fixed between its poles; one end of the armature winding is attached to an insulated terminal and the other to the core itself, thus being in metallic connection with the cylinder. In the air gap between the armature and poles an iron shield is placed, consisting of two segments, connected at the ends and provided with pivots; this is oscillated by a rod from a crankpin in the sparking cam fixed to the half-speed shaft, thus varying the magnetic flux through the armature coil and

generating a current. The spark is produced by a contact breaker consisting of an insulated pin projecting into the combustion chamber and a spindle carrying an interrupter arm which is normally held in contact with the pin by a spring acting on an external lever, but is knocked off by a tappet rod raised by the cam and returned by a spring. The circuit is completed through the cylinder and casing. The time of ignition can be varied by a lever which pulls over the lower end of the tappet rod. The speed of the engine is regulated by a centrifugal governor which operates a butterfly valve placed in the inlet pipe, so throttling the mixture and reducing the compression. When extra power is required the governor may be put out of action and the engine allowed to race.

The cylinder and valve box are cooled by a water-jacket surrounding them. Lubricant is supplied to the crank chamber to be distributed by the splashing of the crank. The engine is started by a movable winch handle engaging with a pin on the shaft, a cock on the cylinder head being opened to reduce the compression, which is normally 70 lb. per sq. in. The total weight of the motor is 186 lb. The petrol consumption of such motors varies from 0·8 to 1·6 pints per brake h.p. hour. M.3410.

446. Four-cylinder petrol motor. Presented by Messrs. Humber, Ltd., 1914.

This is a sectioned example of a 16 h.p. motor-car engine of the 1910–11 pattern. It has four cylinders, 100 mm. (3·94 in.) diam. by 130 mm. (5·12 in.) stroke, cast in pairs, with water-jackets surrounding the cylinders and valve-chambers. The valves have flat seats; the inlet valves are on one side of the cylinders and the exhaust valves on the other. The two cam shafts are driven from the crankshaft by noiseless chains, and each valve spindle is operated through a short lever, one end of which is pivoted to the casing while the other end rests on the cam. The crankshaft has bearings between all the cranks, and forced lubrication is provided by a rotary pump placed in the crank chamber, and driven through a vertical shaft by a worm on one of the cam shafts. A relief valve is fitted to prevent excessive oil pressure, and fresh oil is fed into the crank chamber through a long vertical pipe fitted with a float that indicates the oil level therein. A high-tension magneto is fitted and is driven from one of the cam shafts by a chain; brass tubes are mounted over the cylinders, through which the ignition cables are led to the sparking plugs. The thermo-siphon system of cooling is adopted. M.3992.

447. Brillié petrol motor. Lent by Messrs. A. Turner & Co., Ltd., 1913.

This a skeleton engine of the form patented by Mons. E. Brillié in 1897, and fitted to the Gobron-Brillié motor cars. Each two-cylinder unit gives an impulse for each revolution of the crankshaft, and the rotating and reciprocating parts are balanced.

The cylinders, which are placed vertically, are long and open at both ends, while each contains two pistons, moving in opposite directions, and having a common combustion chamber between them. Two cylinders are placed side by side and the lower pistons are directly connected with a long crankpin on the shaft below; the two upper pistons are connected together by a rocking cross-head which has a connecting rod at each side driving on to a pair of crankpins set at 180 deg. with the other pin. The explosion takes place in each cylinder alternately, but as the pistons move in unison, lateral as well as longitudinal balance is secured. The outer cranks are shorter than the inner one in order to compensate for the greater mass of their moving parts. The pistons moving away from one another give a rapid expansion of the gases.

In the example shown, which is the 40-60 h.p. size, two pairs of cylinders are used, with their cranks set at right angles to one another. The cylinders are 110 mm. (4·33 in.) diam. by 200 mm. (7·9 in.) stroke. M.4264.

448. Four-cylinder petrol motor. Lent by the Daimler Motor Co. (1904), Ltd., 1910.

This is a specimen of the form of petrol motor patented by Mr. C. Y. Knight in 1905 and 1908, and adopted as their standard engine in the latter year by the Daimler Co. It differs from the ordinary type in that the usual mushroom tappet valves are replaced by sliding sleeve valves, fitted between the piston and the cylinder wall. This form of motor runs quite silently, and, owing to the rapid opening and closing of the valves, very high speeds can be attained; the absence of valve pockets in the combustion chamber is a further advantage, while reduced weight and increased flexibility are claimed for it.

The engine has four water-jacketed cylinders 96 mm. (3·78 in.) diam. by 130 mm. (5·12 in.) stroke, cast in pairs and bolted to the crank chamber. Near the upper end of the cylinders, ports are formed through the walls and jackets, leading to the inlet and exhaust pipes. Within the cylinder are fitted two concentric cast iron sleeves which are extended into the crank chamber and there attached by connecting rods to short cranks on a countershaft running at half the speed of the crankshaft. The inner one of these sleeves is 4 mm. (0·158 in.) thick, and the outer one is 3 mm. (0·118 in.) thick, their stroke being 1 in. They are pierced near their upper ends with slots extending round nearly one half of the circumference, and these slots, when they coincide with one another and with the cylinder ports, put the cylinder into communication with the inlet or exhaust pipe. The piston works inside the inner sleeve. The cylinder heads are cast separately and water-jacketed, while they have cylindrical portions projecting into the sleeves and cylinders as far as the cylinder ports. These extensions are fitted with packing rings which provide a tight joint between them and the inner sleeves. Clearance chambers are formed in the heads and the sparking plugs are fitted in their tops. The half-speed shaft is driven by a silent pitch chain, and has a worm upon it which drives the magneto and water pump. A small plunger pump, worked by one of the valve rods, maintains the pressure in the fuel tank. A flywheel is fitted to one end of the engine shaft, and this serves as one member of a cone clutch. A float-feed carburetter of the multiple jet type is fitted, and the mixture is controlled by a throttle valve. The motor is rated at 22 h.p. M.3718.

449. Valveless two-stroke petrol motor. Presented by the Day Motor Co., Ltd., 1913.

This is an example of the two-stroke valveless motor patented by Mr. J. Day in 1891. It operates on the Clerk cycle (*see* No. 450) but has no inlet or exhaust valve, the piston itself serving as a valve when passing over three ports formed in the cylinder wall.

The engine has a single vertical cylinder 3·25 in. diam. by 3·25 in. stroke and develops 2·5 h.p. when running at 900 r.p.m. The cylinder is cast in one piece with its head and water jacket, and is bolted to a cylindrical crank chamber provided with supporting wings. The ends of the crank chamber are closed by dished covers which reduce its volume, and carry long solid crankshaft bearings which are lined with white metal and lubricated with grease so as to be airtight. The ascent of the piston causes a partial vacuum in the crank chamber, and when near the top of its stroke its lower edge uncovers a port communicating with the carburetter, and thus permits the mixture of air and petrol to rush into the crank chamber. The descent of the piston then compresses the charge in the crank chamber to a pressure of 3 or 4 lb. per sq. in.; when near the bottom of its stroke its upper edge first uncovers the exhaust port and next the inlet port which communicates with the crank chamber, so that the products of combustion are expelled and the fresh charge introduced during a very short period. The charge is compressed on the next up stroke and fired by an electric spark. A projecting lip on the piston deflects the entering mixture upwards to prevent it from passing directly to the exhaust port, but there is an appreciable

loss in this way especially at low speeds. For this reason, and on account of the difficulty in getting the charge in and out of the cylinder in the short time available, this type of engine does not give double the power of a four-stroke engine of the same size, but only about 50 per cent. more at the normal speed, and even less at higher speeds. The mean effective pressure is about 60 lb. per sq. in.

A specially compact form of spray carburetter, having a hand-adjusted needle jet, is attached to the crank chamber inlet port, and this is provided with a non-return valve. A heavy flywheel is fitted to one end of the crankshaft and the ignition contact maker is placed behind it; a long lever is provided for varying the point of ignition. The engine can be run with paraffin if fitted with a suitable carburetter, and it will run equally well in either direction. It weighs, complete, 70 lb. Inv. 1913–164.

450. Lucas's two-stroke petrol motor. Made by the Valveless Car Co., Ltd. Received 1911. Plate VIII., No. 5.

The advantage of obtaining an impulse in every revolution of an internal combustion engine, and so increasing the power for a given cylinder capacity, was early recognised, and many engines of this class, working on the cycle patented by Sir Dugald Clerk in 1881, were made commercially prior to the expiry of the Otto patent in 1890; they were then abandoned, however, owing to the great simplicity of the Otto cycle engines. The rise of the petrol motor and the invention of the valveless type by Mr. J. Day in 1891, have caused the two-stroke engine to be largely used for small powers where extreme economy of fuel is of little moment, while the great value of the system for high-power gas engines has led to its adoption both in the valveless form and in that with valves, the increased complication being of less importance in these. The Diesel oil engine is also made in the two-stroke form, for which it is well adapted. In the Clerk two-stroke cycle the exhaust and suction strokes of the Otto cycle are eliminated, the burnt gases being expelled and the fresh charge introduced, by the aid of an auxiliary pump, when the piston reaches the end of its outward stroke. The mixture is then compressed on the inward stroke and fired in the usual way. In small engines the piston itself, in conjunction with a closed crank chamber, forms the pump, but in large engines separate pumps are provided.

The petrol motor shown is of the valveless form and was patented by Mr. R. Lucas in 1904–9; it has two vertical water-jacketed cylinders 5·25 in. diam. by 5·5 in. stroke, placed side by side and connected by a common combustion chamber. The pistons move together and drive separate parallel crankshafts which are geared together so that they rotate in opposite directions and thus secure a balance of the moving parts. The crankshafts are off-set from the axes of the cylinders so that the pressure comes more directly on the connecting rods, and there is less lateral pressure on the cylinders walls. The crankshafts run in ball bearings and each carries a flywheel; one of these forms the outer member of a cone clutch that connects the motor with the change speed gear. Side wings are formed on the crank chamber to support the motor on the car framing. The inlet and exhaust ports are formed as slots through the cylinder walls and are uncovered by the pistons as they approach the bottom of their stroke. The inlet port is placed in one cylinder and the exhaust port in the other, the latter opening in advance of the former. The incoming charge thus sweeps completely through both cylinders, so that better scavenging is obtained than in the single-cylinder valveless engine, and less loss is occasioned by part of the fresh charge passing directly to the exhaust. The carburetter is bolted on one side of the cylinders, and contains a petrol jet kept closed normally by a needle valve which is attached to the centre of a diaphragm valve that admits air to the crank chamber when the up stroke of the pistons reduces the pressure in it. The petrol jet, the level of which is kept constant by a float and needle valve, opens into the passage connecting the crank chamber with the cylinder inlet port, so that

when the air valve lifts, the petrol valve is opened, and a small quantity of petrol enters this passage. The point of the petrol valve is wedge shaped, so that when it opens, the jet area increases at a greater rate and gives the correct proportion of air and petrol. On the down stroke of the pistons the air is slightly compressed so that, when the inlet port opens, the air passes into the cylinders carrying the petrol vapour with it. Regulation is effected by a throttle valve fitted to the inlet passage below the petrol jet. The crank chamber communicates, through a non-return valve, with the petrol tank to give a pressure feed. A high-tension magneto is used for the ignition, one sparking plug serving for both cylinders. When starting the compression is reduced by opening a valve near the top of the cylinders. Forced lubrication is provided for by an oil pump fitted with a distributer that delivers the oil to the cylinders and bearings in turn ; the oil supplied to the main bearings finds its way to the connecting rod ends through holes in the crank-pins. A transverse shaft, rotated from one of the crankshafts by skew gearing, drives the magneto and oil pump, and also the cooling water circulating pump. A belt-driven fan produces a current of air through the radiator.

The motor develops 25 h.p. when running at the normal speed of 800 rev. per min. A feature of these engines is their large torque at low speeds, and the large range of speed—150–2,300 rev. per min.—over which they will run. A motor of this size has developed over 40 h.p. at 1,750 rev. per min. M.3835.

451. Motor-bicycle engine of 3·5 h.p. Presented by the Triumph Cycle Co., Ltd., 1912. Plate VIII., No. 6.

This is a sectioned example of the standard air-cooled petrol engine used on the Triumph motor cycles; its single cylinder is 85 mm. (3·35 in.) diam. by 88 mm. (3·46 in.) stroke, and has a piston displacement of 499 c.c.

The cylinder is cast with deep and thin radiating fins round its upper part, including the valve chamber, parts of the fins being cut away to accommodate the valve springs. It is mounted on a two-part aluminium crank chamber, which encloses the pair of flywheels, and is secured by four studs. The piston is a light casting with a dished top, and is fitted with a packing-ring near each end; the gudgeon pin is a tapered driving fit in it. The crankshaft runs in ball bearings, and is fitted with large and well balanced flywheels. The valves are mechanically operated, and are interchangeable; they are driven by internal cams formed on a pair of spur wheels placed one on either side of a pinion fixed on one end of the crankshaft. Each valve stem is lifted by an adjustable tappet rod having a rotating head placed eccentrically with the stem; the tappet rests on one arm of a bellcrank lever, the other arm of which carries a roller that engages with the cam. An exhaust valve lifter is fitted so as to act on its bellcrank lever. The belt pulley has one flange fixed on the crankshaft, while the other flange is mounted on a left-hand screw thread so that its position may be adjusted, thus varying the effective diameter and giving a range of gears from 4·25 : 1 to 6·25 : 1 ; the flange is locked by a right-hand nut. The sparking plug is fitted above the inlet valve, and the engine is mounted in the cycle frame by means of suitable lugs formed on the crank case. M.4158.

452. Two-cylinder motor cycle engine. Lent by Messrs. Douglas Brothers, 1913.

This air-cooled petrol motor for bicycles was introduced in 1907 and embodies improvements patented by Mr. W. Douglas in 1911. It has two horizontal opposed cylinders 60·5 mm. (2·38 in.) diam. by 60 mm. (2·36 in.) stroke, and has a capacity of 345 c.c.; the pistons drive opposite cranks on a shaft placed between them and the flywheel is outside the crank case.

The cylinders are bolted to the central crank case and are provided with horizontal cooling fins. All the valves are one side of the engine, those for each cylinder having parallel spindles inclining downwards towards the cam shaft, which is placed below the crankshaft and driven from it by spur gearing. The cams are fitted behind the gearing and drive adjustable

eccentric valve tappets through pendent levers pivoted on the enclosing casing. The exhaust valve levers are extended downward and their lower ends may be acted upon, so as to open the valves when necessary, by short levers operated by a Bowden wire and hand lever. A float-feed spray carburetter, fitted with sliding throttle and extra air valves, is fitted, and the main air entering round the jet is drawn through a pipe leading from the fins of the back cylinder. A high-tension magneto is placed on top of the crank case and is driven by enclosed spur gearing from the crankshaft. All the controls are by Bowden wire and lever.

The engine develops 2·75 h.p. when running at 1,600 rev. per min. When fitted to the bicycle, it is fastened by two clamps to the lower horizontal member of the frame, and drives by a chain to a countershaft, and from thence to the rear wheel by a belt. Inv. 1913–11.

453. Two-cylinder "Precision" petrol motor. Presented by Messrs. F. E. Baker, Ltd., 1914.

This is a two-cylinder air cooled petrol motor of the form much used on high powered motor bicycles.

The cylinders are 70 mm. (2·76 in.) diam. by 85 mm. (3·35 in.) stroke, their capacity being 654 c.c. The engine develops 6 h.p. when running at about 2,000 rev. per min. The cylinders are arranged in a vertical plane and inclined to one another at an angle of 50 deg.; the two piston rods are connected with the same crankpin which is fixed between a pair of balanced flywheels. The valves and sparking plugs are situated in the cylinder heads, the valve seatings being removable; the upper part of the cylinders are well provided with radiating fins. The flywheels are enclosed in an aluminium crank case to which the cylinders are bolted, and a cover projecting on one side encloses the valve cams and timing wheels. The cams actuate the valves through bellcrank levers and long rods connected with horizontal lever pivoted on brackets bolted to the cylinder heads; the closing springs are fitted round the valve stems. The exhaust valves are provided with a hand lifting arrangement for releasing the compression when starting the engine. The carburetter fits on to a T pipe between the cylinders, and a pair of pipes carry the exhaust gases to a silencer placed below the engine. The magneto is fitted on one side of the crank case and is driven by an enclosed chain from a sprocket wheel on the end of one of the cam shafts. The complete engine would weigh 84 lb. Inv. 1914–2 and 8.

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454. Motor-cycle carburetter (1903). Lent by Messrs. Brown and Barlow, Ltd., 1911.

This example of a single jet carburetter is the first one made by this firm. The jet is placed at the bottom of a vertical chamber which is contracted round it, air being drawn in through holes in the bottom of the chamber. The level of the petrol is kept constant by a float and needle valve placed in an adjacent chamber, to the bottom of which the petrol inlet pipe is attached. At the top of the mixing chamber is a perforated cone upon which the petrol spray impinges, and above this is a hand-controlled cylindrical throttle valve which controls the supply of gas to the engine. An auxiliary air valve, for regulating the mixture when necessary, is arranged at one end of the throttle, and is operated by a separate handle. M.3951.

455. Automatic carburetter. Presented by the Stewart Precision Carburetter Co., Ltd., 1913.

This is an example of the carburetter patented by Mr. A. C. Stewart in 1905, 1910 and 1911. It is designed to give a constant proportion of petrol to air at all speeds and loads, which it does by means of a suction lifted air valve controlling the petrol supply; it also gives a rich mixture for starting.

The carburetter is very compactly constructed and consists of a float chamber surmounted by a casing containing the air valve, above which is attached the mixing chamber and butterfly throttle valve. The float chamber contains an annular float hinged at one side and acting directly on the petrol inlet valve above it. The central casing is formed with a cylindrical guide for the air valve, and the bottom of this is closed so as to form a dash-pot to prevent oscillation of the valve. The valve itself is formed with a large conical head and a hollow cylindrical stem, a short tube extending from the bottom by which petrol is admitted to its interior; this tube fits over a tapered pin projecting upwards from the bottom of the float chamber, and this regulates the petrol supply, as any lift of the valve increases the area of the opening round the pin. In the centre of the valve stem, and reaching from near the bottom almost to the top, an aspirating tube is fixed and air passages are formed in the valve to lead air from below the seating to a cylindrical chamber surrounding the upper part of the tube. This chamber leads up to a narrow horizontal chamber having for its exit a circumferential slot just above the valve seat. Air admission ports are formed through the central casing.

With the throttle closed, the valve rests on its seat, and the petrol inlet is open sufficiently to permit the petrol to enter the lower part of the valve stem. When starting, the suction of the engine draws this petrol up the aspirating tube, while a small quantity of air passes by the main valve so producing a rich mixture. When running, as the throttle is opened, the air valve will lift a proportionate amount, so that the air and petrol openings will correspondingly increase, while the vacuum above the valve remaining practically constant causes the rate at which the petrol passes the regulating pin to remain constant also, with the result that the proportion of air to petrol will be constant for all positions. Adjustment for slow running is made by varying the position of the taper pin, while the high speed adjustment is made by changing the pin for one with a different taper. The mixing chamber is provided with a jacket through which hot water or exhaust gases are passed.

The carburetter shown has an outlet 1·25 in. diam., and is suitable for four-cylinder engines having cylinders from 75 mm. (2·95 in.) to 85 mm. (3·35 in.) diam. Inv. 1913–137.

456. Variable jet carburetter. Lent by Messrs. White and Poppe, Ltd., 1911.

This is a carburetter of the form patented by Mr. P. A. Poppe in 1906. It has an adjustable petrol jet which, in conjunction with the throttle valve, gives a constant mixture under varying load, while the general design leads to sufficient uniformity under varying speeds with a given throttle opening.

The carburetter has a vertical cylindrical mixing chamber cast in one with the float chamber and having the air inlet on one side and the mixture outlet on the other. The petrol jet projects from the bottom of the mixing chamber, and is completely surrounded by a cylindrical throttle valve which has circular holes cut through it, opposite to one another, and corresponding with the air and mixture openings. The throttle is rotated between adjustable stops by a hand lever, and is itself surrounded by a sleeve forming part of the cover of the chamber. This sleeve has holes corresponding with those in the throttle, and it can be turned through a small angle so as to reduce the air inlet and thus enrich the mixture over the whole range; it is held in position by two clamping nuts. The jet consists of a vertical tube with a conical top in which a hole, out of centre, is drilled, and over it a cover with a similar hole fits closely. The cover is connected with and turns with the throttle, so that while the two holes coincide when the throttle is fully open, the closing of the throttle also reduces the jet opening in proportion. For slow running on no load, with the throttle closed, air is admitted through the hollow spindle of the valve, the opening being adjusted by means of a revolving plate with a spiral outline. The petrol valve counterweights in the float chamber

take the form of rollers so as to reduce friction. Hot air is supplied to the carburetter from a sleeve surrounding the exhaust pipe.

The example shown has an induction opening 30 mm. (1·18 in.) diam., and is suitable for engines having cylinders up to 127 mm. (5 in.) diam.

M.3940.

457. Multiple jet carburetter. Presented by Messrs. Trier and Martin, Ltd., 1910.

The simple form of jet carburetter (*see* No. 454) is unsuitable for modern petrol motors, which have a large range of speed, as it gives too rich a mixture under the increased air suction at high speeds; means have, therefore, to be provided for maintaining an approximately constant proportion of petrol and air under all conditions of running, and the specimen shown, which is of a type introduced in 1907, illustrates one method of doing this.

The carburetter has three petrol jets, a combined throttle and auxiliary air valve, and a suction operated air valve in the main airway. The main air inlet is at one end, and the passage from it contracts to a narrow neck which causes the air to pass with a high velocity over the vertical petrol jets which are arranged in line at its lower side; the usual float chamber, with the petrol inlet, is bolted on below the jets. The neck leads to an enlarged cylindrical mixing chamber, which has an air port cut through it at one side and a passage near the end leading to the induction pipe of the motor. Within the mixing chamber there slides a tubular throttle valve, having ports cut through it, which permit the mixture to pass into the induction pipe; this valve also regulates the size of the auxiliary air inlet. The throttle valve has fixed to it a smaller tube, which slides in the neck over the jets, and so brings one or more of them into use, according to the position of the throttle, which is operated by a spindle and lever. The mixing chamber is jacketed with hot water, and the jets are readily accessible through an opening, which is closed by a small cover clamped by one screw. The main air inlet is adjustable, and the suction valve at its centre consists of a flat plate connected with the cover by a closely coiled spring; increased suction of the air draws in the plate, expanding the spring and admitting more air between its coils. One jet is sufficient, using the air through the main inlet, to keep the engine running slowly with the throttle nearly closed. When more power is required the throttle is opened, and this brings into action the second jet and also opens the auxiliary air port in the mixing chamber; further motion of the throttle uncovers all the jets and opens wide the air port. With the throttle in a given position, an increase of speed will automatically open the suction valve, thus admitting the necessary extra air. When the throttle is pushed right in, it shuts off all the jets and admits pure air only into the cylinders.

M.3803.

458. Automatic carburetter. Presented by the S. U. Co., Ltd., 1914.

This carburetter, designed to give automatically the correct mixture under all conditions of running, was patented by Mr. G. H. Skinner in 1905 and 1907. It operates by maintaining a constant velocity of the air past the petrol jet, the air passage and the jet orifice being automatically varied in correct proportion in accordance with the requirements of the engine. A carburetter of this kind gives economy of fuel with great flexibility of the engine.

The carburetter has a jacketed vertical mixing chamber, into the bottom of which the petrol jet enters at an angle of 45 deg. The air passage past the jet is blocked by a piston placed concentrically above the jet. This piston is free to slide up or down in a cylindrical guide, and carries at its upper end a disc that forms the bottom of a bellows suction chamber, while its lower end carries a tapering needle which penetrates the centre of the petrol jet. The upper edge of the bellows is connected with the cover of

a surrounding chamber, and a pipe connection is made between it and the upper part of the mixing chamber below a butterfly throttle valve fitted there. When the engine is running slowly, unloaded, the piston gives a minimum air passage and a proportionate jet area. As the throttle is opened and the suction increases, the piston and needle are drawn up, giving the necessary increased air and petrol supplies. With the piston in its highest position a clear passage from inlet to outlet is given. The float chamber is mounted so that it may be turned round the jet connection to any position.

The example shown is suitable for engines with cylinders 85 mm. (3·35 in.) diam. M.4163.

459. Zenith carburetter. Lent by Messrs. Fenestre, Cadisch & Co., 1911.

This is an example of the automatic carburetter patented by Mons. F. Baverey in 1907. It has an ordinary jet which gives an increasing ratio of petrol to air under increasing suction, and a second jet which gives a constant flow of petrol quite independent of the air flow. It is found that such a jet gives a decreasing ratio of petrol to air which just compensates for the increasing ratio given by the ordinary jet, so that the two together produce a mixture of the desired constant proportion under all conditions of running, and this without any additional moving parts.

The main jet, fed from an ordinary float chamber, is placed at the bottom of a vertical mixing chamber having the usual air inlet and choke tube, and butterfly throttle valve. The compensating jet is arranged concentrically with and surrounding the main jet, and it is fed from the bottom of a vertical tube or well open to the atmosphere at the top and communicating, at the bottom, with the float chamber, through a plug with a small hole which delivers petrol at the desired uniform rate under the constant head in the float chamber. Thus the second jet, under all conditions, can only deliver the amount of petrol fed into the well. A tube fits closely inside the well and has a helical slot cut through it; this communicates at one point with a vertical slot, cut in the side of the well, which leads to a small hole opening into the mixing chamber just under the edge of the throttle valve when in its closed position. On starting the engine, with the throttle nearly closed, the petrol in the well will be at the same level as that in the float chamber; the strong suction past the edge of the valve will draw the petrol from the well and ensure a good starting and slow running mixture. When the throttle is opened further, the main and compensating jets come into full action, the level of the petrol in the well falls, and so cuts off the supply to the starting jet at a point which can be adjusted by rotating the inner tube. A glass window is provided to ascertain the correct level in the float chamber, and part of the air supply to the carburetter is heated by passing through a muff surrounding the exhaust pipe.

The example shown has an outlet 36 mm. (1·42 in.) diam., and is suitable for a four-cylinder engine having cylinders of 95 mm. (3·74 in.) diam.

M.3950.

460. Scott-Robinson carburetter. Presented by Messrs. B. M. & W. D. Fair & Co., 1911.

This is an example of the automatic carburetter patented by Mr. M. Scott-Robinson in 1907. It is of the variable jet type, and has a single air inlet, the area of which is varied with that of the jet in such a manner that a mixture of constant quality is obtained under all conditions.

The float chamber, mixing chamber and jet are cast in one piece; within the mixing chamber is a hollow regulating float of a certain weight, with a solid cone-shaped base and a series of small holes near its lower edge, which fits over the petrol jet and is held in position by a dash-pot or guide within which it is an easy sliding fit. The interior of this float contains a tapered needle, suspended in the jet orifice, and held by a screwed carrier so that its

height may be accurately adjusted. The float rests normally on a seating at the bottom of the mixing chamber and acts as an air valve; it is lifted by the suction of the engine to such a height as will pass the required quantity of air at the designed constant velocity. The air being drawn past the holes in the float creates a partial vacuum within it, which causes the petrol to flow from the jet and out through the holes, where it meets and mixes with the air, thus forming the explosive mixture. The float on rising lifts the needle and allows to pass the correct amount of petrol which is required to give the right proportion of petrol and air, the needle being accurately formed for this purpose. The air on its way to the carburetter passes through a sleeve fitted round the exhaust pipe of the engine and is thus warmed.

It is stated that this carburetter renders an engine extremely flexible, allowing it to be throttled down to a very low speed while instantly picking up when the throttle valve is opened, and that the petrol consumption is also very low. M.3846.

461. Claudel-Hobson carburetter. Lent by Messrs. H. M. Hobson, Ltd., 1910.

This is an example of the automatic carburetter patented by Mr. C. H. Claudel in 1907–8; it produces a constant mixture, under varying load and speed, by the aid of a combined air and throttle valve, a special jacketed petrol jet, and a single air inlet.

The carburetter is very compact and is formed in one casting having the petrol inlet and float chamber at one side, and the air inlet, petrol jet and mixing chamber close beside them. The petrol enters through a gauze filter, and its admission is controlled by the usual needle valve and float; it passes to the jet through a wide channel, which is jacketed with hot water. The jet consists of a vertical nozzle surrounded by an outer jacket or tube which has holes drilled through it at the level of the nozzle outlet and also at the bottom; a screwed plug closes the top of the jacket over the nozzle. The throttle and air valve is a horizontal hollow plug, the centre of which is level with the top of the jet, having portions cut away at the top and bottom, in a particular manner, to permit the passage of mixture and air. When the throttle is nearly shut, the top of the jet is enclosed within it, and the petrol is sucked through the top holes of the jacket, the suction being relieved by air which passes up inside the jacket. When the throttle is open to any extent the air valve is correspondingly opened, air being drawn in mainly round the outside of the jet in correct proportion to the petrol, as provided for by the shape of the air inlet. For any position of the throttle an increase of speed will cause a rapid flow of air through the jacket, so preventing the mixture from becoming too rich. Two screws are provided by which the richness of the mixture can be adjusted. M.3810.

462. Polyrhoe expanding carburetter. Lent by Polyrhoe Carburetters, Ltd., 1911.

This is an example of the carburetter patented by A. G. Ionides and J. W. Goddard in 1908–9. It produces a mixture having a constant proportion of petrol to air, under all conditions of load and speed, by automatically varying the size of the air and petrol inlets in constant proportion, the suction of the air on the jets remaining practically constant. It has two simple and independent adjustments, one for running the engine slowly on no load, and the other for varying the mixture to suit the atmospheric conditions or the quality of petrol being used.

The carburetter has a horizontal cylindrical barrel to one side of which is bolted a petrol chamber containing a float and needle valve. Midway along the top of the barrel is a rectangular opening or throat through which the air enters, and along one side of this opening 25 minute horizontal jets are arranged, from which the petrol is drawn by the air as it passes across them. The petrol passes from the bottom of the float chamber through a sheet of

felt acting as a filter, and then through a number of small ducts which open out near the edge of the throat. The jets are slots, 0·025 in. wide, cut in sheets of brass, ·006 in. thick, which are clamped down over the ducts so that the jets point towards the throat, and each communicates with a separate duct. A slide valve, moving at right angles to the axis of the barrel, is mounted in guides opposite the jets, and by adjusting its position, by means of a Bowden wire and hand lever on the dash-board, the width of the throat can be varied until the best ratio of air to petrol is obtained. The length of the throat in use is automatically determined by the position of a block fitted across the throat and attached to a piston sliding within the central part of the barrel. This piston is connected, by a tubular rod, with a larger piston working in the closed end of the barrel; the suction of the engine lowers the pressure behind the large piston, and allows the air pressure to force it back against a spring, so that under increased suction the throat is made larger and at the same time brings into action a proportionate number of jets, only those jets being operative past which the air is flowing. When the engine is running slowly under no load, a richer mixture is provided by setting one of the slide valve guide-bars so that it cuts off a large part of the air flowing past the first few jets.

A hand-operated throttle valve slides in the other end of the barrel, and regulates the area of the mixture outlet which is placed above it. The barrel is heated by a water jacket connected with the cylinder jackets. A feature of this carburetter is that the jets can be seen in operation. The example shown is suitable for an engine having four cylinders 4 in. diam., rated at 25 h.p. M.3948.

463. "Solex" carburetter. Lent by Messrs. S. Wolf & Co., Ltd., 1913.

This two-jet automatic carburetter introduced in 1913 is an improvement on that patented by Messrs. H. V. J. Jouffret and J. M. Renée in 1909. It is designed to give a constant mixture under all conditions, and is constructed so as to be very easily dismantled.

The carburetter has a special form of atomising main jet placed in the usual position, and an auxiliary jet placed in the upper part of the float chamber. The main jet gives the correct mixture for high speeds with full throttle opening, the auxiliary jet being then entirely cut of use. The auxiliary jet practically forms a separate small carburetter which supplies the mixture for starting and slow running, while for immediate throttle openings it supplies the petrol necessary to make up any deficiency due to the reduced flow from the main jet. The main jet is surrounded by a double sleeve forming a narrow sinuous passage through which air is drawn to mix with and atomise the petrol issuing from it.

The air inlet, mixing chamber and throttle valve are fixed to the cover of the float chamber, which also carries the petrol inlet valve and union. The float chamber and base carrying the main jet are in one piece, and this is clamped to the upper part by a single nut screwed on to a central hollow stem fixed in the float chamber. The auxiliary jet is fitted to the top of this stem, and receives part of its air through a narrow space surrounding the neck of the clamping nut, and the remainder through a ball valve fitted to a passage formed in the nut. The function of the ball valve is to reduce the air suction on the auxiliary jet when the speed increases. The jets can be taken down without breaking any pipe joints.

The example shown has an outlet 23mm. (0·91 in.) diam., and is suitable for engines with cylinders up to 70mm. (2·76 in.) diam. Inv. 1913–176.

464. Semi-automatic carburetter. Presented by Messrs. Brown and Barlow, Ltd., 1914.

This is an example of the variable jet carburetter for motor bicycles, patented by Messrs. C. Brown and C. W. Graham in 1907, 1912, and 1913.

The necessary constancy of the mixture is obtained by means of a cylindrical throttle valve mounted concentrically above the petrol jet and controlling both the air inlet and mixture outlet; a tapered needle is attached to the centre of the throttle, and this enters the jet opening so as to vary the petrol outlet as the throttle is raised or lowered. On the outlet side of the throttle and mounted within it, is an extra air valve which controls 40 per cent. of the air opening while the throttle itself controls the remaining 60 per cent. The carburetter is run normally on the throttle only, the extra air valve being either closed or opened to the amount necessitated by the atmospheric or running conditions. The jet is surrounded by a small choke tube, and the spraying air is drawn through holes at the bottom; tho jet opening is covered by a cap perforated on the engine side, and this ensures proper vaporisation and prevents the petrol from being blown out at the air inlet. A notch is cut in the lower edge of the throttle to give the small opening required for slow running. In order to adjust the carburetter to suit various engines, a number of small air holes are drilled through the mixing chamber wall below the throttle, and these can be uncovered as required by a spring ring. The valves are operated by Bowden wires and self-locking levers, the returning springs being arranged within the valves.

The carburetter shown fits on to an inlet pipe 1·125 in. diam.

Inv. 1914–17.

465. Senspray carburetter. Presented by Messrs. Charles H. Pugh, Ltd., 1912.

This form of spray carburetter, for motor bicycle engines, was patented by Mr. G. F. Bull and the makers in 1911–12. In it the petrol is atomised by a small injector nozzle, through which a small volume of air is drawn at a high velocity by the suction of the engine, and the explosive mixture is formed with more air that flows in round the nozzle. The carburetter is semi-automatic in its action, but is also provided with an auxiliary air-valve which enables the mixture to be accurately adjusted to suit all conditions of running.

The carburetter has a straight horizontal body, with a conical inlet at one end, and across this, at mid-length, a cylindrical throttle valve is fitted, which has a hole through it giving a clear passage throughout when fully open. The spraying nozzle is mounted in the centre of the inlet and the petrol jet enters this at the narrowest portion of its coned interior, which is close up to the throttle valve. The valve is surrounded by a concentric shutter, which, when closed, cuts off the upper half of the spray and air inlets. The inlet opening of the throttle, which gives the main air control, is notched at the lower edge to provide the necessary opening when the auxiliary air-valve is closed. The jet is mounted on the end of an arm projecting from the bottom of the float chamber, and may be removed by unscrewing it. The carburetter body is clamped on to a boss surrounding the jet.

The petrol enters the bottom of the float chamber through a conical valve which is lifted against its seating, as the float rises, by means of a spring clip on its stem. A spring button is fitted to the cover of the float chamber, and, when depressed, opens the valve and floods the carburetter.

The whole carburetter is supported by its outlet end which is clamped to the inlet pipe of the engine. A gauze cap is placed over the air inlet, and the throttle and auxiliary air-valves are operated by Bowden wires from self-locking levers fitted to the handle bar.

The carburetter shown is suitable for 2·5 h.p. single cylinder engines, or up to 7 to 9 h.p. twins. M.4146.

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466. Ignition coil and accumulator. Presented by Messrs. C. A. Vandervell & Co., 1914.

Electric ignition was first practically applied to the gas engine in 1860 by Lenoir who used Bunsen batteries and a Ruhmkorff coil, but it was only

partially successful on account of the failure of his sparking plugs. Carl Benz successfully applied it to his petrol motor-cars in 1885, using accumulators and an induction coil, and its advantages over the hot tube ignition, then in general use, led to its adoption by others, so that by 1900 its use on motor-cars was universal. Tube ignition rendered the motor practically inflexible, whereas the electric spark will fire a weaker mixture, thus allowing governing by throttle; it also permits the time of ignition to be varied, so that the power and speed can be largely regulated. The danger of fire is also removed. The coil and accumulator system continued in general use until about 1906, when it was largely displaced by the high-tension magneto (*see* No. 468), which enables the engine to generate its own current and eliminates battery troubles. The system is now used on motor-cars mainly as a standby, and for starting the engine when the magneto is giving a weak spark. Modern examples of coils and accumulators show the great advance that has been made in their construction so as to render them reliable and durable.

The trembler coil shown is of the ordinary construction, but is provided with an easy means of adjusting the trembler blade. It is entirely enclosed in a wooden case arranged for fixing on the car dash-board. Three terminals are provided, one being connected with the accumulator, another with the sparking plug, while the third is earthed to the car-frame, which forms the return for both primary and secondary circuits.

The accumulator which is of the Faure type consists of two 2-volt cells connected in series. Each cell consists of a transparent celluloid case, containing two positive and three negative plates; the negative plates are so formed that the active material is all in one piece, as though held in a basket, and cannot fall out. The plates are separated by perforated celluloid sheets, the terminals are sealed by rubber plugs, and the top openings are closed by similar plugs fitted with glass vent tubes; spray arresters are fitted below the vents. A metal case is provided for carrying the accumulator. The example shown has a capacity of 40 ampère-hours on ignition, or 30 ampère-hours on a continuous discharge at 1 ampère. M.4159–60.

467. Lodge ignition coil. Lent by Messrs. Lodge Bros. & Co., 1911.

This form of coil, which produces what is known as the "B" spark, was patented in 1903 by Sir J. Oliver Lodge, F.R.S., and Mr. A. M. Lodge; it is largely used for igniting the explosive mixtures in internal combustion engines, for which purpose it is very efficient, as the spark is unaffected by soot, oil or moisture.

The apparatus consists of an ordinary induction coil with its trembler; the two ends of the secondary coil, besides being led to the ordinary spark gap, are also connected with the inner coatings of a pair of Leyden jars of small capacity, the outer coatings of which are connected with the sparking plug in the motor cylinder. The outer coatings are also short-circuited by a partial conductor or "leak," consisting of damp blotting paper in a sealed glass tube, which permits of the charging of the condensers, but obstructs a rapid flow of current. When the ordinary spark occurs, the contents of the condensers are liberated, causing an impulsive rush of current which surges, with extreme rapidity, along the leads and across the gap, producing a spark which is unaffected by the leak or by defective insulation in the leads. It will also operate if the sparking points are wholly immersed in water, and will fire very weak mixtures.

The example shown is for multi-cylinder engines and is fitted with two tremblers, either of which may be used; a reversing switch is also provided. M.3812.

468. High tension magneto. Made by the Simms Magneto Co., Ltd., 1911. Plate IX., No. 1.

The high tension magneto electric machine for igniting the explosive mixture in internal combustion engines was introduced about 1903, and rapidly found favour, as it combines the advantages of the magneto generator with those of the simple sparking plug. The example shown, which is for a four-cylinder engine, is of the form now general, in which the primary and secondary coils are wound on a rotating armature, and the contact breaker and distributer are combined in one machine.

The machine has two double horseshoe magnets, fastened to a non-magnetic baseplate, and having separate pole pieces bolted to them. The armature is of the shuttle type and its spindle runs in ball bearings. The low tension winding consists of a comparatively few turns of thick wire, one end of which is connected with the armature, and thus to the magneto frame, while the other end is led through the hollow spindle of the armature to the fixed terminal of the contact breaker, which is insulated and fitted with a platinum pointed screw. The moving part of the contact breaker is a bell-crank lever, with a platinum point on its inner arm, pivoted near the edge of a disc which is fixed to and in electrical connection with the armature. The whole contact breaker revolves with the armature, and contact, which is maintained by springs, is broken twice in a revolution by the outer arm of the lever striking against two rollers mounted on a timing lever, which can be partially rotated so as to adjust the time of ignition. The condenser is fitted to the end of the armature, under the contact breaker. The high tension winding, composed of a large number of turns of fine wire, has one end connected with the primary winding, and through this to the magneto frame, while its other end is connected with a slip ring from which the current is collected by a carbon brush in a vulcanite holder, and led thence to the distributer. The distributer consists of a slab of vulcanite fixed to the magneto frame, having a chamber formed in it which contains a rotating vulcanite holder with a carbon brush that sweeps over four contacts each connected with a socket terminal at the top of the block. The brush holder is rotated, through spur gearing, at one-half the speed of the armature, and as the armature rotates at the same speed as the motor shaft there are two sparks in each revolution of the latter, delivered to each of the four cylinders in turn. The secondary current is conveyed to the distributer by a spring-supported carbon brush bearing on the end of a metal core contained in the stem of the brush holder. A safety spark gap, consisting of brass sparking points with a suitable air gap, is placed between the high tension circuit and the magneto frame; this prevents damage to the armature should the circuit be interrupted. The cover of the contact breaker is insulated and is electrically connected with the insulated terminal of the same by a contact spring. The cover is connected, through a spring blade and terminal, with one terminal of a single pole switch, the other terminal of which is connected with the magneto frame. This switch, when closed, puts both ends of the primary circuit to earth, and so renders the machine inoperative.

The magneto is made so as to be easily dismantled and reassembled, the gears and contacts being well enclosed. The example shown is suitable for four-cylinder engines up to 20 h.p. M.3952.

469. Bosch sparking plug. Presented by E. A. Forward, Esq., 1913.

This is a two-point sparking plug, for petrol motors, constructed in the manner patented by Mr. R. Bosch in 1907.

The insulation surrounding the central electrode has a shoulder formed at mid-length, the lower part being smaller in diameter and cylindrical, while the upper part is made conical. The shoulder rests on a seating formed in the body of the plug, a copper-asbestos washer being interposed to make the joint gastight and a brass ring is driven tightly into the space between the coned insulation and the cylindrical body; the top edge of the body is then turned over inwards to secure the ring and insulation in place. The central electrode has a collar near its lower end, and this is drawn up against the insulation by nuts on its upper end which forms the terminal

Two wire points project from the inner end of the body towards the central electrode and forms the spark gap. Inv. 1913–128.

470. Sparking plugs. Presented by Messrs. H. M. Hobson, Ltd., 1913.

The sparking plug is an appliance used to form an electric spark for igniting the charge within the cylinder of an internal combustion engine. It consists generally of a metal socket screwed into an opening in the cylinder, and having one electrode fixed to its inner end, while the other electrode is fixed to the end of a central metal stem surrounded by insulation secured gas-tight in the socket. The points of the electrodes are set a short distance apart so that an intense spark is produced when a high tension current is passed through a circuit containing the plug. The examples shown embody improvements patented by Messrs. M. Pognon and E. A. H. de Poorter in 1902 and 1909 respectively.

These two plugs are for magneto ignition and have their electrodes both bent over and set so that they lie side by side for a short distance, but not parallel to one another. This arrangement gives a spark gap of variable width, which allows the spark to take the shortest path when starting the engine and running at low speeds, but with higher speeds it can choose a longer path; the wear of the electrodes is also reduced, so giving them a longer life.

The larger, or car size, example has the usual outer steel socket, with a clamping gland for securing the insulation, but the insulation is made as three separate pieces of porcelain, so as to obviate all difficulties due to expansion. The inner porcelain is seated on a copper and asbestos washer placed at the bottom of the socket, and is held down by a collar on the stout central brass stem. The second porcelain bears on the top of the collar and is itself held down by the gland, while the third porcelain is pressed down on top of the gland by a nut on the stem. Asbestos washers and packings are inserted between the porcelains and the adjacent metal, and the socket is lined with mica to complete the insulation. The end of the inner porcelain is reduced in diameter and has a deep central well, so forming large air gaps between the insulation and the metal, and preventing short circuiting by carbon deposits.

The smaller plug is for motor cycles; it is similar to the larger one, but the insulator is in two parts instead of three. M.4170.

471. Lodge sparking plug. Presented by E. A. Forward, Esq., 1915.

This form of sparking plug for petrol engines was patented by Mr. B. Hopps in 1909.

The central electrode is a stout nickel rod fixed to the end of a steel spindle of large diameter, which is screwed into the insulating plug, a copper asbestos washer being placed between the top of the insulator and a collar on the spindle. The insulator has shoulders formed on it for securing it in the outer steel shell, and its inner end projects between the central electrode and the shell. Asbestos washers are placed on the shoulders, and the top of the shell is spun over a ring bearing on the top washer. A waist is formed round the insulator, and the space thus formed is filled with a vitreous enamel which unites the metal and insulator so as to form a gas-tight joint. The outer electrode consists of a nickel ring having three projecting points; this is set in a groove at the nose of the shell. Inv. 1915—18.

MECHANICAL MEASURING INSTRUMENTS.

Under this heading are included the various appliances used in measuring the different quantities entering into the execution of industrial work: the more delicate instruments employed in scientific investigations are not represented, as they form an independent collection which is arranged elsewhere in this Museum. As the applications of the results of scientific investigation extend, the number of measuring instruments used in the arts continually increases, a change that is particularly noticeable in connection with the rapid adaptation of electricity to industrial work.

Number.—The measurement of number is the simple duty performed by the counter found in nearly all registering instruments; by this mechanical counting an enormous amount of monotonous mental labour is avoided and the possibility of error greatly reduced, while the labour of attendants is almost entirely dispensed with. The chief element is some form of revolution counter, consisting usually of a series of trains of wheels with a step ratio of ten to one, or an equivalent; this is now generally so arranged that the advance is intermittent instead of continuous, so that the reading is not complicated by figures in intermediate positions.

Length.—In the measurement of length, from the time when three good barleycorns formed the standard inch, the necessity for some more accurate unit of measurement has been continually experienced; such progress has, however, now been made that, for all practical purposes, standards of length of sufficient accuracy are generally available for reference. In London there is a series of English units, arranged for public use on the north wall of Trafalgar Square, while elsewhere in the Galleries of this Museum is exposed a shorter series of both English and metrical units. The relative merits of comparison by sight and by end measurement have been frequently discussed, as both systems have advantages, but the higher results as regards accuracy have been secured by the end measurement system. For rough measurements we all use sight methods, and by magnifying the readings the accuracy of this very convenient system can be enormously increased; but, for general mechanical work of high accuracy, end measurement is chiefly relied on, although in many instances the two systems are combined. Sir Joseph Whitworth developed the present system of end measurement, and generally introduced it into workshop practice, at the same time applying it to the construction of machine tools and gauges, which he thus brought to a degree of accuracy that has not since been materially improved.

Volume.—For measuring volume we usually determine the dimensions of the containing reservoir or receptacle; but, where fluids are supplied by measurement, or where the quantity discharged has to be recorded, meters of some form are usually

employed. Gas meters, whether wet or dry, really record the number of times that a certain vessel, in the form of a cup or bellows, is filled by the gas passed, a method equivalent to measuring the contents of a tub by bailing it out by a vessel of known capacity. Positive water meters work on the same principle; but a very large class of water meters register from the velocity with which the water issues from a constant orifice, this velocity being usually determined by the rotation of a fan; small rotating fans are also generally used for measuring the quantity of air passed for ventilating and similar purposes. In the measurement of large quantities of water, as in the case of rivers and streams, the velocity may be determined approximately by floats or fans, but where the water flows over a weir or through a notch, the velocity is more readily determined by accurately measuring the head of water over the sill.

Mass.—The mass of a body is the property upon which its weight depends, and in all industrial work the weight is the quantity determined. There are three types of apparatus in use for weighing, of which the oldest is the scales with equal armed beam and standard weights; this is still the most accurate method, but for heavy weights becomes so inconvenient as to be practically impossible. The second plan is by varying the leverage, as with the old steel-yard; the third and most generally employed system is a combination of the two preceding ones, and is seen in the various forms of modern platform weighing machines. The estimation of weight by the compression produced on a calibrated spring is a convenient method of determining mass, but does not admit of the same accuracy as the lever machines. Duckham's machine is a very compact form of spring balance, and is capable of dealing with the heaviest loads while they are being lifted; in it the spring is that within the pressure gauge upon which the reading is taken.

Velocity.—Speed indicators, for the determination of velocity, form a very large class of instruments, but in the majority of cases in the arts the rate of revolution of some shaft is the quantity that has to be determined, and for this purpose the centrifugal force arising from the speed is generally the quantity most easily measured. Watt's pendulum governor in a much modified form, and generally spring loaded, is the acting mechanism in most tachometers, although a revolving mass of fluid is sometimes preferred. For temporary purposes, speeds are generally determined by the aid of a watch and some counting device, while in a few forms of speed indicator these two instruments have been combined in one apparatus.

Fluid Pressure.—The earliest steam gauges in use were columns of water or mercury, usually contained in a U-tube, and such arrangements, being exceeding accurate, are still generally employed for testing the ordinary modern gauge, in which the measurement relies on the elasticity of some form of spring. Gauges have also been used in which the pressure is indicated by the compression of a volume of air contained in a closed glass tube, mercury acting the part of a piston, but the correction for temperature is so large that this arrangement is but

seldom resorted to, except for very high pressures or in experimental work.

The ordinary steam gauge, in which the pressure is indicated by the movement of an index over a graduated dial, remains the most convenient appliance for measuring fluid pressure. In the earliest form of this class of gauge, movement of the finger was derived from that of a piston loaded with a spring, but very soon the piston was replaced by a diaphragm (*see* No. 567). In 1849, however, Eugène Bourdon (b. 1807, d. 1884) replaced the diaphragm by the now generally used elliptical tube; it was afterwards simplified by magnifying the movement by toothed gearing (*see* No. 568).

Properties of Materials.—Testing machines, for determining the elasticity and ultimate strength of materials used in construction, are now of the greatest importance, since economical design can only be carried out when the properties of the materials employed are known with sufficient accuracy; moreover, frequent testing is the only certain way of securing that the materials approximate sufficiently to the intended standards. During recent years a great improvement has been made in testing machines, in addition to their increase in size and accuracy, by the employment of an automatic recording apparatus by which a diagram is drawn showing the rate of extension as the load increases.

Temperature.—For the measurement of temperature, mercury-in-glass thermometers remain the most convenient and accurate instruments for practical use, where the temperatures are not too high. Owing to the certainty of its graduations the gas thermometer is generally used as a standard of reference. During recent years a great advance in the measurement of high temperatures for industrial purposes has been made by the introduction of electrical arrangements, some of which depend upon the variation with temperature of the electrical resistance of platinum, while in others thermo-electric couples are employed which, combined with delicate galvanometers, give readings capable of being registered by self-recording attachments at any distance from the furnace.

Work.—The measurement of work done or energy expended has always been of importance, but came into prominence more particularly after the invention of the steam engine. Watt found that his engines were frequently required to do work that had long been performed by animal power, so to determine the work that a horse could do, he made the animal pull a weight of 150 lb. upward from a coal pit, by means of a rope passing over a pulley; this weight the horse lifted at the rate of 220 ft. per min., thus doing work equal to 33,000 ft.-lb. per min., which result was the final estimate that Watt adopted as his "horse-power," although he knew that a horse could not regularly give out so much energy. When, however, Watt's engines were paid for by their horse-power, he complained that "the power of a horse is growing to that of an elephant," so that even his ample allowance did not satisfy all parties. Recent experiments in traction have shown, however, that although Watt's estimate

of the average power of a horse was exceedingly liberal, yet in emergencies and on hills the average horse exerts for considerable periods a very much greater effort than Watt estimated, a deduction that is confirmed by the large reserve of power with which motor cars have to be provided. To measure the power of the work done by his engines Watt introduced the steam engine indicator (*see* No. 588), and this instrument, greatly improved and modified to meet the requirements of present steam engine practice, remains by far the most important appliance for the measurement of work. Watt's indicator is, however, only applicable to power generated or transmitted by fluid pressure; for other purposes some form of dynamometer must be used. These are of two kinds: the positive absorption type, where the work done is transformed into heat, and the inferential transmission type, where the work done is to be usefully used. Baron Prony's absorption apparatus of 1821 had two beams clamped to the shaft and prevented from turning, the frictional resistance being balanced by a weight. This has been improved so as to make it compensated, and very accurate results are obtainable with it. Mr. Froude brought out an efficient water brake in 1877. The essential part of transmission dynamometers for tractive resistance is some form of calibrated spring. For shafts the elastic deformation is measured by optical (*see* Naval Engineering Section) or electrical means. If the transmission is electrical, the readings of instruments are relied on.

Measurement of Number.

472. Watt's engine counter. Contributed by James Brown, Esq., 1861.

When Messrs. Boulton and Watt were introducing their improved steam-engine for pumping in the Cornish mines, payment in many cases was made by the pumping work performed. This work was recorded by a counter, fixed on the engine beam, and constructed to register the number of strokes performed. It is stated that the mine owners objected to the readings of these instruments, on the ground that they counted the short strokes of the engine equally with the complete ones.

The apparatus consists of a locked box containing a pendulum which, by a reversed escapement, drives a series of counting wheels; indexes on the spindles of these wheels register the number of oscillations on a series of dials advancing in powers of ten. M.526.

473. Revolution counter. Presented by the Institution of Civil Engineers, 1868.

This is an old form of revolution counter. The gearing consists of a worm and worm-wheel, together with a train of spur-wheels for reducing the speed, and three dials over which four indexes move continuously but not all in the same direction, so that the reading is difficult, particularly at high speeds. M.1082.

474. Revolution counter. Presented by the Institution of Civil Engineers, 1868.

This is an old counter, similar to No. 473, but it has the driving spindle enclosed in a long wooden arm (apparently a later addition), at the outer end of which the worm and worm-wheel are arranged. The worm spindle terminates in a knuckle joint that has been driven by a rotating wire. M.1083.

475. Five-figure revolution counter. Contributed by R. Roberts, Esq., 1858.

This instrument, invented by Mr. Roberts, consists of five wheels, each marked with the ten numerals on the edge; all but the first wheel run loose on the horizontal shaft of the counter. On one side of each wheel is a ten-pointed recess, and on the opposite side of the wheel is an eccentric boss; on each boss is a loose ring from which projects downward a tail that prevents its rotation, while from the face of the ring three teeth, which engage in the recesses in the adjacent wheel, project. The result of this connection is that each wheel is driven at one-tenth of the speed of the wheel driving it, so that read along a horizontal line the revolutions are indicated in a very convenient form for reading; the advance of each wheel is, however, continuous, so that the trouble of half figures is not avoided. Inv. 1858–10.

476. Revolution counter. Contributed by R. Roberts, Esq., 1862.

This counter indicates by the use of two concentric revolving dials geared together by an epicyclic train. The dials are on a central fixed stud, which also carries a double-ended pointer. The larger dial has a toothed edge and is driven by a worm from the shaft whose revolutions are to be counted; the ratio of the gearing is 1 : 100, so the dial counts up to 100 rev. The dial carries at the back a pin, upon which runs a long pinion gearing into a spur wheel of thirty-nine teeth fixed to the stud, and also into a wheel of forty teeth secured to the back of the inner dial. By this means the inner dial, which reads up to 4,000, is rotated at 1-40th of the speed of the outer one. M.726.

477. Electrical counter. Wheatstone Collection, 1884.

This instrument, patented by Sir C. Wheatstone in 1858, consists of two dials over which pointers are moved by gearing from a step-by-step propulsion actuated by an electro-magnet. The poles of the latter are adjacent, and between them oscillates a magnetised needle carrying the arbor of a ratchet wheel of fifteen teeth, which engages with a fixed pawl and is thus slowly turned by the currents received; this motion is recorded by a counter. M.2170.

478. Revolution counter. Lent by R. Applegarth, Esq., 1879.

This is a pocket counter, patented by Mr. A. Sainte in 1877, provided with fittings by which it will readily connect with any revolving shaft, if the end be accessible. When this is not the case a small wooden roller, the circumference of which is one-tenth of a yard, is slipped on the counter and employed to measure the circumferential velocity of the shaft, pulley, or belt. A small plumb-bob is also included which can be used as a seconds pendulum for giving the time. The instrument is provided with a handle so that it can be pressed against the revolving shaft, and the motion obtained drives a single worm that gears into a lower worm-wheel of 100 teeth, having a graduated disc. On the spindle of this wheel is a pinion of ten teeth gearing into a wheel of 100 teeth, the disc of which is also graduated, the total ratio being

such that one revolution of the hundreds dial corresponds with 1,000 rev. on the shaft. The arm carrying the worm-wheel is hinged, so that the whole counter can be thrown out of action without removing it from the shaft, or the gear can be disengaged for bringing the dials to zero. M.2514.

479. Counter. Contributed by W. Smith, Esq., 1876.

This is a counter invented by Mr. J. Norton. It is actuated by a reciprocating motion and the index and number dials move intermittently, so that there is no uncertainty through the display of half figures. The operating lever has a pawl mounted upon it that drives a ratchet wheel on the spindle of the index, which reads units and tens. There are also six small rotating numbered dials, showing figures through holes in the front plate, which carry the reading to 100,000,000. The first of these has on its spindle a ratchet wheel driven by a pawl actuated by a snail-cam on the index spindle, while a single tooth on the first spindle drives intermittently a wheel of ten teeth on the second, and so on throughout the series. Light springs, engaging with secondary toothed wheels on the spindles, hold them stationary between the movements. M.1444.

480. Six-figure counter. Lent by Messrs. Schäffer and Budenberg, 1888.

This is an instrument arranged for counting either reciprocating motions or revolutions; it contains a vibrating lever, to which motion may be given direct, and also a crank by which the lever may be vibrated when it is desired to count revolutions. A toothed wheel on the spindle of the dial containing the unit figures is driven by the lever by means of a movement very similar to the escapement of a clock reversed. Another wheel on the same spindle, having one tooth only, drives intermittently a wheel with ten teeth on the spindle of the tens dial, and so on throughout the series. M.1906.

481. Revolution counter. Lent by Messrs. W. H. Bailey & Co., 1888.

This is an instrument for counting the number of revolutions made by an engine, etc. An external lever is actuated by some reciprocating part, and by means of a pawl works a ratchet wheel on the spindle of the central index, which records units and tens on the principal dial. Six smaller dials give the higher multiples of ten up to tens of millions, the hands of these being driven from the central spindle. M.1946.

482. Revolution counter. Lent by Messrs. Trier Bros., 1888.

This is a five-figure counter on the intermittent system, patented by Mr. A. Kaiser in 1883.

The figures are placed on the peripheries of wheels, and the movement of the unit figure wheel is effected, as in Watt's and many other counters, by a reversed escapement; a crank-pin engaging with a slotted lever secured to the pallets imparts the necessary reciprocating motion to the latter. A single tooth attached to the axis of the first wheel drives, intermittently, a wheel with ten projecting teeth, and so on throughout the series. Each of the figured wheels is locked during the intervals between the step movements by a projecting rim, on the preceding driving wheel, passing between the overhanging teeth. M.1894

483. Taximeter. Lent by W. H. Beck, Esq., 1909.

Instruments for indicating to the passenger the fare due for the hire of a carriage were suggested and tried many years ago, but they did not come into practical use until quite recent times, at first on the Continent, and later

with the advent of the motor cab, in this country. The example shown is of German origin and was patented by Herr A. Grüner, in 1895. It contains mechanism for indicating the fare, both for distance travelled and time waited, and it also shows, for the protection of the proprietor, the number of journeys made, the total distance covered, and the total of the fares earned. It is able also to record at five different rates, higher rates being charged for more than two persons, also for night and country journeys. The mechanism is entirely enclosed so that it cannot be tampered with by the driver, who has power only to set the apparatus in position for recording at its various rates.

The front of the casing is provided with openings through which the recording figures are seen; there are four counters recording respectively: the amount payable for the journey, the total fares earned, the total distance travelled, and the number of journeys made. The fare counters are driven by levers actuated by a star wheel which is continuously rotated, through ratchet clutches and gearing, either by mechanism operated by the carriage wheel or by a clock when the vehicle is stationary. The differential rates are obtained by means of a cam-moved lever which accelerates the rotation of the star wheel by giving it intermittent pushes by means of a pin; the stroke of this lever is variable and is regulated by a stepped ring against which its end comes into contact. This ring is attached to the axis of a drum upon which are marked the fare conditions, and this is turned into the required position by an external handle. As the drum has to be rotated once for every journey, it is used to actuate the counter recording the number of journeys made. The distance recorder is worked from one of the spindles driven by the carriage wheel so that it is independent of the time mechanism. The internal mechanism is driven by a reciprocating rod projecting through the casing and worked by an external cam driven by the carriage wheel; this rod is caused to rotate a ratchet wheel which has to be suited to the diameter of the carriage wheel. A small metal flag is attached to the taximeter to indicate whether the carriage is for hire or not.

When disengaged, the flag arm is upward and the rate indicating drum is set at "free"; in this position the counting mechanism is out of gear and the fare counter is at zero. On being engaged, the driver sets the drum at the required position, which action sets the counter at the minimum fare and puts it into gear for recording. The drum movement also releases the flag arm and enables him to lower it. At the end of the journey, the driver turns the drum to the "counting" position, which puts the counter out of action again but retains the figures at the fare to be paid. On raising the flag arm, the drum can be turned back to the "free" position, which sets the counter back to zero. M.3714.

Measurement of Length.

484. End measuring instrument. Watt Collection, 1876. Plate IX., No. 4.

The principle of this instrument is the same as that employed in the most accurate of modern measuring machines.

There are two jaws, one fixed to a slide, and the other movable by a fine threaded screw. A pointer attached to the screw registers on a graduated dial fractions of a revolution, and a pinion working into the screw records the number of complete turns. M.1814.

485. Micrometer. Maudslay Collection, 1900.

This end-measuring machine was made early in the nineteenth century by Henry Maudslay while engaged in his labours in the development of accurate machine tools. As Sir Joseph Whitworth was employed for some years in Maudslay's works, it is probable that the refinements that he

introduced into mechanical measurement were influenced by this same instrument.

The micrometer consists of a gunmetal bed on which slide two saddles fitted with end-measuring faces, and also having bevel-edged slots through which graduations on the bed can be read. One of the saddles extends through the bed and forms a split nut that, by set screws, can be delicately tightened upon a horizontal leading screw of 100 threads to the inch. This screw has a collar on it that is held against a stationary abutment, beneath the bed, by a plate adjusted by screws, so as to eliminate the end play. The end of the leading screw has a milled head with a graduated edge of 10 divisions each subdivided into 10, so that each subdivision indicates a displacement of the saddle through 0·0001 inch. M.3118.

486. Whitworth's workshop measuring machine. Made by Messrs. Sir J. Whitworth & Co., 1871.

The celebrated millionth measuring machine shown by Sir Joseph Whitworth at the 1851 Exhibition is so sensitive as to be unsuited for ordinary workshop use, so the form here shown, in which the graduations correspond with an alteration in length of 0·0001 inch is that generally preferred.

The machine has a cast iron bed and two headstocks resembling the loose headstocks of a lathe, but instead of pointed heads each head has a flat one. One headstock is fast, while the other is movable along the bed by a quick pitched bed-screw, and its centre or measuring end is adjustable by a screw within the headstock. The fast headstock has its measuring end moved by a screw of 20 threads to the inch, and to this screw is attached a wheel whose circumference is divided into 500 divisions. In using the machine for workshop purposes, it is usual to set the heads by placing between them a standard gauge as near the required dimensions as is available, and then to fix the final position of the measuring ends by moving one end through the required difference by means of the divisions on the wheel. M.1671.

487. Micrometer calliper gauge. Made by the Brown & Sharpe Manufacturing Co. Received 1915.

This is a small example of the micrometer gauge patented by the makers in 1878 and 1884.

It consists of a U-shaped frame having one fixed flat-nosed measuring point and another moving point forming the end of a screw which works in a long tapped hub projecting from the frame. The screw is protected by a hollow sleeve attached to its outer end and passing over the hub. The screw has 40 threads per inch and the hub has a scale of 40 divisions to the inch engraved on it, so that one turn of the screw moves it endwise through one division or 0·025 in. The edge of the sleeve is bevelled and is divided circumferentially into 25 parts; each division, when it passes a longitudinal line on the hub, indicates that the screw has made 0·04 of a turn and the gauge opening has increased or decreased by 0·001in. Fractions of a thousandth can be readily estimated. The hub is split, and has a conical nut on its end which can be tightened up to compensate for wear of the screw. The fixed point is screwed into the frame so that it can be adjusted for wear of the measuring faces. The frame has engraved on it the decimal equivalents of fractions of an inch, and the capacity of the gauge is 0·5in. Inv. 1915—24.

488. Rope gauge. Presented by T. H. Court, Esq., 1914.

This is a form of calliper gauge, probably used by ship riggers.

The body of the gauge is of boxwood while the sliding blade and jaw are of brass. The front of the blade is graduated to read the circumference of

the rope directly, while the back reads the diameter. The faces of the gauge are engraved with tables giving the weights, per fathom and per coil, of ropes of given circumference, as well as the weight of chains. Inv. 1914—896.

489. Vernier calliper gauge. Made by Messrs. J. Chesterman & Co., Ltd. Received 1915.

This is an engineers' calliper gauge for both inside and outside measurement; it is fitted with verniers for accurate reading.

It consists of a blade to which one jaw of the calliper is fixed while the other jaw slides along the blade and may be clamped in any position. Fine adjustment is provided by a screw fixed to a sliding jaw and passing through a nut attached to a clamp which also slides along the blade. The jaws and blade are made of hardened cast steel. The front of the blade is divided in inches and millimetres, and the verniers on the sliding jaw read to 0·001 in. and 0·02 mm. The jaws are parallel at their ends and are 0·5 in. wide when closed, that width having to be added to the scale reading for inside measurements. The gauge has a capacity of 12 in. Inv. 1915—287.

490. Micrometer. Presented by Mrs. Hertha Ayrton, 1909.

In this experimental instrument by Profs. W. E. Ayrton and J. Perry, a magnifying spring of the type used in their electrical measuring instruments is arranged to form a sensitive micrometer, reading to 0·00005 in.

Two jaws are urged together by a spring, and the upper jaw is at one extremity of a lever which, at its other end, is attached to a vertical magnifying spring. The lower end of the spring carries a pointer moving above a horizontal scale, and is secured to a flexible fibre passing around an adjustable rod below. The lever magnifies any movement of the upper jaw eight times. A sensitive spring is employed, which is 0·0025 in. diam. and is made of phosphor bronze. M.3626.

491. Metric gauges. Presented by Mons. F. Pétrément, 1862.

These are steel discs with gauge notches cut in them for use in ascertaining the thickness of wire, sheets, etc. The steps rise by tenths or hundredths of a millimetre. M.1669.

492. Screw gauges. Lent by Messrs. Taylor, Taylor, and Hobson, 1893.

These specimens show the system of standard gauges introduced to insure that the screwed connections of photographic apparatus shall be interchangeable.

No. 1 is a double calliper gauge for external threads—one side gives the standard, in this case 1·5 in. diam., and the other 1·499 in. diam., the difference being the amount allowed on external screws to secure an easy fit and absolute interchangeability, any work exceeding these limits being rejected. No. 2 is a double gauge for internal screws, one end being 0·001 in. larger than the standard, so that any screw cut to it shall readily fit any screw passed by the external screw gauge. No. 3 is the chaser employed for cuting the threads, and it is equally capable of cutting both internal and external threads. It has two grooves, of the shape of the thread, cut on it externally, and is provided with a central hole by which it can be attached to a tool-holder. One-fourth of the circumference is cut away so giving two cutting edges, one of which is used on external screws and the other for internal ones.

To overcome the difficulty of entering these fine threads and also to avoid the risk of stripping them, the first half of the thread—where it is incomplete—is cut away, so giving an abrupt commencement but a thread of full strength. The internal threads are treated in the same way, and an arrow head is stamped on the two portions so that they can be placed together in the position in which the curtailed threads will at once engage. Nos. 4 and 5 show a pair of threads so treated. No. 6 is a standard screwed ring in steel provided with an index mark on each side. Its thickness is such that when screwed on, the index marks the commencement of the complete thread so that by marking and finishing fittings to this gauge it is secured that all fittings shall screw up to the same position, thus ensuring that lenses or diaphragms shall occupy their intended parts in any camera. M.2551.

493. Workshop gauges. Lent by the Newall Engineering Co., 1907.

These gauges are of the type used in the interchangeable production of machine parts wherein a definite departure from standard size either way is permitted.

The "limit" of accuracy is determined by the different sizes of the two ends of the gauge, one end of which will "go" and the other "not go." The allowable departure from standard size, depending on the class of work produced, and also whether the fit is to be running, pushing, or driving, is standardised as shown on the adjoining cards and not left to the judgment of the workman as in the older method. A 1·5 in. diam. internal plug gauge, a 1·5 in. external gauge, a 1·5 in. and a 4 in. double setting bar illustrate this.

In the adjustable external limit gauge shown, which was patented by Mr. W. J. Newall in 1902, the usefulness of such gauges is greatly increased by having one of each pair of measuring anvils on the crescent-shaped casting screwed for adjustment. These are first set, by the standard setting bar shown or otherwise, and then an index forced into one anvil and a dial into the other. The anvil with the dial is turned till the desired higher limit is read off and is then clamped; the dial and index are interchanged and the other anvil set to the lower limit. This gauge will take sizes between 3·5 in. and 4 in.

In the internal micrometer, which was patented in 1902 by Mr. J. E. Storey, three legs at 120 deg. to one another have anvils at the outer ends and are bevelled at the inner ends to suit a bevelled axial micrometer screw arranged with a milled head and sleeve for direct reading to 0·001 in. This gauge will take sizes from 5 in. to 5·5 in. M.3477–9.

494. Adjustable gauges. Lent by H. M. Budgett, Esq., 1910.

These are specimens of the adjustable external and internal gauges patented by Mr. F. W. Windley in 1908. By such an arrangement considerable economy in first cost, and in the space occupied by a set of gauges, is secured.

The gauges are made in halves having large circular flat faces, which are held together by a stud and two nuts placed in apertures formed in the parts. Different distances between the measuring faces are obtained by interposing between the parts one or more discs of various thicknesses. These discs are threaded on the stud and are clamped by one solid nut and another split nut, which, when loose, can slip over the threads, but, when tightened, is closed by its conical nose entering a corresponding recess in the gauge. Nine discs are provided from 0·015625 in. to 1 in. thick, and these in combination give 163 sizes with the external gauge, and 99 sizes with the internal gauge. The discs are very accurately ground and different combinations may be checked against one another.

The same arrangement is applied to limit gauges, which can also be used as standard gauges by simply turning one half through 180 deg.

M.3785.

495. Thickness gauge. Made by Messrs. J. Chesterman & Co., Ltd. Received 1915.

This is an engineers' thickness gauge or feeler used for measuring the widths of narrow gaps or clearances.

It consists of a number of steel blades of different thicknesses fitted into a case and hinged at one end so that they fold down like the blades of a pocket knife. In this example there are ten blades, $1\frac{1}{2}$, 2, 2, 3, 4, 6, 8, 10, 15 and 25 thousandths of an inch thick; they are 4 in. long and 0·5 in. wide. The case is graduated in inches and millimetres for use as a rule.

Inv. 1915—284.

496. Wedge gauge. Made by Messrs. J. Chesterman & Co., Ltd. Received 1915.

This is an engineers' gauge for measuring the width of narrow spaces which are deep enough for the insertion of a wedge.

It consists of a handled steel wedge of rectangular section tapering to a sharp edge. It is graduated on the two faces, the thickness at each graduation being marked on it. One side reads from 0·01 in. to 0·15 in. rising by 0·002 in., and the other side from 0·03 mm. to 4 mm. rising by 0·05 mm. Inv. 1915—285.

497. Angular gauge. Made by Messrs. J. Chesterman & Co., Ltd. Received 1915.

This is an engineers' gauge for testing or adjusting callipers; it is used with testing machines or in general work.

It is composed of three steel plates tapering in a fixed ratio, and numbered and divided accordingly; these are placed one on top of the other and fixed to a base plate. The top plate measures from 0 to 1 in., the second from 1 in. to 2 in., and the third from 2 in. to 3 in., the readings rising by 0·01 in. Inv. 1915—286.

498. Combination standard gauges. Made by C. E. Johansson. Received 1919.

This is a set of slip gauges of the form patented by M. C. E. Johannson in 1901 and 1908. The gauges are made with exactly parallel and perfectly plane measuring faces, and are so accurate in size that a number of them may be added together to form a gauge of any size from 0·2 in. to 8 or 10 in., rising by 0·0001 in.

The surfaces of the gauges are so perfect that, when assembled, they will, if sufficiently clean, adhere to one another and may be manipulated as conveniently as a single piece. The accuracy of the gauges is proportional to their size, being one hundred thousandth part of their length, so that the accuracy of a single slip is the same as that of a number of slips forming a gauge of the same size; also two or more gauges of the same size may be made up by different combinations. The gauges are made of selected Swedish carbon tool steel; they are hardened throughout and are subjected to a special treatment which eliminates liability of change of size or shape with time. The gauges are made in sets both for British and Metric measurements. The British set shown comprises 81 slips arranged in four series; the first series consists of 9 slips from 0·1001 in. to 0·1009 in., the second series of 49 slips from 0·101 in. to 0·149 in., the third series of 19 slips from 0·05 in. to 0·95 in., and the fourth series of 4 slips from 1 in. to 4 in.

It will be seen that by the use of these gauges the dimensions of a gauge, jig or piece of work can be determined to an accuracy of 0·0001 in. more simply and conveniently than by any other means, especially when the form of the work is at all complicated. By the aid of certain accessories the gauges may be used for measuring ring diameters and for the accurate scribing of lines or circles. Inv. 1919—

499. Roller gauges. Lent by the Hoffmann Manufacturing Co., Ltd., 1919.

The standard rollers used in Hoffmann roller bearings are made so accurately that they can be used as secondary standard gauges. They are very convenient for setting micrometers or minimeters and also for measuring form gauges.

The rollers have lengths equal to their diameters and are hardened, ground and lapped to within 0·0001 in. of the nominal sizes, both in diameter and length. The rollers, however, are not truly circular in section, so that although a 1 in. roller measures exactly 1in. diam., it will not go into a hole exactly 1 in. diam.; hence they should not be used as plug gauges when a high order of accuracy is required.

The set comprises 15 gaugesr anging from 0·25 in. to 1·25 in., the steps being 0·0625 in. below 1 in. and 0·125 in. above 1 in. Inv. 1919.—227.

Measurement of Volume.

Positive Water Meters.

500. Frost's water meter (working). Contributed by B. Fothergill, Esq., 1862.

This meter was patented by Messrs. Chadwick and Frost in 1857. It consists of a vertical cylinder 4·6 in. diam. by 2·2 in. stroke, fitted with a cup-leather-packed piston. The piston rod extends upward into a valve chest and is provided with two tappets for moving the valve gear, and also with a pawl for rotating the counter. The valve gear consists of two horizontal slide valves one on the other. The upper or auxiliary valve is moved by the tappets on the piston rod through a bellcrank lever, and lets water to and from two small cylinders that contain pistons attached to the lower or main slide valve that distributes the water to the large measuring cylinder below. M.727.

501. Hannah's water meter. Contributed by Messrs. Elgood & Co., 1874.

This water meter, patented by Mr. S. Hannah in 1868, is an apparatus for recording by actual measurement the quantity of water passing, the unit of measurement being the volume swept through by a piston working in a curved cylinder of such a length that the ends nearly meet, the space between the ends being occupied by two curved valve chambers concentric with the cylinder. The curved piston is without rod or other appendage, and at each end of its stroke strikes against and moves a small three-ported slide valve which controls the pressure of water acting on two small pistons attached to the main three-ported slide valve, which controls the admission and exhaust of water for the main piston. The piston, at each end of its stroke, also moves a lever connected with the recording apparatus. M.1323.

502. Kennedy's water meter (working). Lent by Kennedy's Patent Water Meter Co., 1890.

In this positive meter, patented Mr. T. Kennedy in 1852, the measurement is made by registering the number of times that a cylinder of known volume is filled and emptied, by the water passing through the meter.

The vertical measuring cylinder is provided with a piston kept tight by a rubber ring, which rolls between the surface of the cylinder and the bottom of the wide groove in the piston, so avoiding sliding friction. The upper end of the piston-rod is provided with a rack which rotates a pinion connected with the counter and with the valve gear. The pinion carries an arm which catches the haft of a swinging hammer; the arm lifts the hammer until it has passed its

centre, when the hammer falls over by gravity and strikes a finger connected with the valve gear and so reverses the motion of the piston, and similarly on the return stroke. The swinging hammer prevents the valve from stopping in its mid position. A buffer is provided which absorbs any surplus energy in the hammer. M.2303.

503. Frager's water meter. Presented by Prof. H. J. Spooner, 1896.

This construction of positive meter was patented by MM. C. Michel and A. Frager in 1878, and subsequently improved. The water on entering passes through a strainer and is then distributed by two ordinary slide valves to the ends of a pair of vertical cylinders with cup-leather packed pistons. There is a central trunk in each piston which acts as a tappet to a rod within it that moves the valve of the other cylinder just as in a duplex pumping engine. The counter is worked by a tappet on one of the rods. M.2945.

504. Frager's water meter. Presented by the British Meter Co., 1904.

This is a sectioned example of a later form of the meter described in No. 503, and differs from it only in details of construction. The pistons have cage-shaped extensions which make them sufficiently long to be self-guiding, and also enable them to act as tappets for the valve rod. Instead of cup leathers for the pistons, packing rings are used, and springs are employed to maintain the slide valves in close contact with their faces. The meter shown is for a 0·5 in. pipe, and registers in tenths up to 1,000,000 gal. before repeating. M.3367.

505. Model of Dick's water meter (working). (Scale 1 : 4.) Lent by F. W. Dick, Esq., 1893.

This represents a positive meter of the piston type introduced in 1886. The actual meter has four cylinders arranged radially, with each pair of opposite pistons connected by a bar with a square hole in it. In this hole fits a smaller square, formed on the back of a square slide valve working on a flat face in the centre of the machine. In this face is a central exhaust port and four admission ports. Each admission port communicates with the end of one of the four cylinders. The supply water enters the central space and presses on the four pistons, but the slide valve puts the ends of two of the opposite pistons in communication with the supply and discharge respectively, so causing a stroke to be made, and this movement carries the slide valve into the position that causes a stroke of the two pistons at right angles to the former pair. The arrangement is a simple way of forming a duplex engine, as one slide valve by its motion in two directions answers for both. The quantity of water passed is recorded by a counter rotated by a star wheel driven by two pins attached to one of the reciprocating bars, but this detail is not shown in the model. M.2656.

506. Tylor's water meter (working). Lent by Messrs J. Tylor & Sons, 1891.

In this meter, patented by Mr. J. J. Tylor in 1888, the water is measured by two double-acting horizontal cylinders, each provided with a long double piston so that the valve gear can be arranged between its two heads. The upper cylinder has a stroke equal to its diameter, while the lower one, although of the same diameter, has a very short stroke, its main purpose being to actuate the valve of the upper cylinder. At the back of the machine is a cover carrying two slide valves, the upper valve communicating with the ends of the lower cylinder and the exhaust or discharge pipe, while the lower valve similarly acts for the upper cylinder. The water enters the machine at the base

of the central case and leaves through the discharge pipe in the back cover. When the upper piston has nearly completed a stroke in one direction it moves the upper slide valve, thereby causing the lower piston to make a stroke, and in so doing this piston moves the lower slide valve which accordingly causes the upper piston to make a return stroke, and so on, each piston moving the slide valve controlling the other. The pistons are packed with bucket-leathers and are made as light as possible, but buffers on the cylinder covers are provided to stop them at the ends of the stroke. The counter at the top of the case is driven by gearing receiving motion from a ratchet worked by the upper piston. M.2365.

507. Kent's water meter (working.) Lent by G. Kent, Esq., 1890.

In this positive meter, patented by Mr. W. G. Kent in 1889, the measurement is made by registering the number of revolutions performed by a kind of rotary engine through which the water passes.

Within a nearly cylindrical chamber is an elliptical vulcanite piston with a long slot in it, and therefore capable of a combined sliding and rotating motion round a roller fixed eccentrically in the casing. The volume measured is not only the space swept out but also the unoccupied portion of the slot in the piston.

After passing through a conical strainer in the base of the meter the water enters the measuring case through a port on one side and escapes by the opposite port, the piston acting as the slide valve. The motion of the piston is transmitted to a counter fixed at the top of the meter. Owing to the small weight of the vulcanite piston but very little frictional resistance is offered, and no appreciable loss of pressure is sustained by the water in passing through the machine. Two examples for pipe 0·375 in. diam. are shown, one of which is in pieces; they pass 800 gal. per hour and will work with a head of 1 in. A working model with a glass top is also shown. M.2345.

508. Positive water meter (working). Lent by Messrs. Beck & Co., 1902.

This meter, which measures by registering the number of times that three single-acting cylinders are filled by the water passed, was patented in 1894 by Mr. W. A. G. Schönheyder, and is a development of a meter made ten years earlier in which three horizontal cylinders were used.

The water is admitted through a perforated strainer to the upper chamber of the meter, which in the explanatory example shown is formed by a glass cover. The floor of this chamber contains three vertical cylinders, arranged round a central distributing valve, which rolls on a hemispherical seating, through ports in which the water passes to and from the lower ends of the cylinders, and thence by an axial passage into the outlet pipe. This cup-shaped valve has three projecting arms or crossheads, provided with suitable bushes to receive the spherical ends of the piston rods, the piston cups giving sufficient play to permit of a slight deviation from the vertical. In this way the valve is rocked on its spherical seating as the three pistons successively descend, rotation being prevented by projections on the valve which engage in notches on the seating, and the stroke limited by a central collar which restricts the downward movement of each piston. The valve, piston rods, and cylinders are of gun-metal, the valve seating and bushes of vulcanite, and the piston cups of hardened india-rubber. The counting mechanism, which is not shown, is contained in the top cover and driven by a pin projecting from the top of the valve.

The size represented is for a 0·25 in. diam. pipe with a maximum delivery of 100 gal. per hour, but under a pressure difference of 50 lb. it will pass 250 gal. per hour. M.3230.

509. Water meter. Presented by J. Bernays, Esq., 1906.

This construction of positive meter was patented by Mr. Bernays in 1895. It consists of a casting having four horizontal cylinders arranged radially, with each pair of opposite pistons rigidly connected by a flat rod. The centres of the two rods are connected by a short link which controls their movements, its middle point describing a circle round the intersection of the rods; this motion is utilised in driving the circular distributing valve. Four passages are formed in the lower part of the casting, one leading from the outer end of each cylinder to a flat valve face in the central space between them; the valve face has also a central exhaust port discharging below. The supply water enters the central space and presses on the four pistons, but the valve puts the ends of two of the opposite pistons in communication with the supply and discharge respectively, thus causing a stroke to be made, and this movement carries the valve into the position that allows the other pair of pistons to make a stroke. Webs are cast between the cylinders, forming a horizontal partition dividing the supply from the discharge. The outside of the casting is turned to a conical shape and fits into a conical casing which is closed by a cover carrying the counting mechanism, this being driven by a pin projecting from the upper piston rod. The cylinders have gunmetal liners and the pistons are packed with cup leathers. The action of this meter is similar to that of No. 505 adjacent. M.3442.

510. Disc water meter. Presented by the British Meter Co., 1904.

This is a sectioned example of a positive water meter embodying the principle of the disc engine shown in No. 137, in which a disc, gyrating on a conical base within a spherical cavity provided with a fixed partition, becomes the equivalent of a piston in a cylinder.

In the meter the disc or piston is formed of vulcanite, and has a conical lower face which enables the bottom of the spherical chamber to be made flat. In every position of the disc it divides the chamber into receiving and discharging spaces, and the water in the receiving space exerts a pressure on one side, while at the same time less pressure exists on the discharging side. The disc is thus caused to gyrate, and an amount of water is passed at each complete movement equal to the contents of the entire chamber. A rod, projecting upward from the ball forming the centre of the disc, travels in a fixed circular recess, and as it gyrates moves the counting mechanism.

The disc or piston acts as its own valve, its edge passing over openings in the spherical wall of the chamber so situated that they admit and discharge the water at the right portions of the cycle. The water enters the lower part of the meter, then passes through the side wall of the chamber, through the chamber itself, into the upper portion of the case and thence out through the side passage.

The example shown is for a 0·5 in. pipe, and it registers by tenths up to 1,000,000 gal. before repeating. M.3368.

511. Disc water meter. Presented by the Leeds Meter Co., Ltd., 1909.

This is a sectional example of a water meter in which the volume is measured during the passage of the water through the working chamber which is of the disc engine type (*see* No. 137).

The vulcanite disc is conical and has a ball centre upon which it gyrates; the containing chamber is formed with a flat bottom, a conical top and spherical sides. A rod projects upwards from the centre, through a circular orifice, and drives the counting mechanism; its upper end is guided by a vulcanite roller. The working chamber has a partition at one point and a slot is cut in the disc to accommodate it. The inlet and outlet are formed on either side of the partition, which, with the disc, divides the chamber into four spaces: two of

these are receiving while the others are discharging, so that there is a continuous flow. The chamber is fitted with a relief valve to obviate breakage of the disc by shock. The entering water passes through a strainer and then has to pass up through a narrow annular passage on its way to the working chamber. A feature of this meter, like No. 518, is that the counting mechanism is flooded by the water. The meter is constructed throughout of non-corrosive materials, the gearing being of nickel; the dial is of the transparent type (*see* No. 518).

The example shown is for a 0·5 in. pipe, and the mechanism registers up to 10,000,000 gal. before repeating. M.3591.

Inferential Water Meters.

512. Siemens water meter. Contributed by Sir C. W. Siemens, 1858.

This form of rotary meter was patented by Sir C. W. Siemens in 1852; it is of the inferential class, in which the passage of the water causes a fan to revolve and so give a reading, from which the quantity is deduced by the results of previous experiments.

The meter shown is arranged as a short length of pipe, on the side of which is a case containing a counter with six dials. Within the pipe are two cylindrical drums provided with helical blades, those of the first drum being right-handed and those of the other, left; so that as water flows through the pipe these two drums revolve in opposite directions; they are, however, geared together and also to the counter. At each end of the pipe and beyond the drums is a pointed block, fixed by three ribs and so arranged as to give a parallel flow to the water. The instrument is graduated by noting the readings after a known quantity of water has passed. M.166.

513. Siemens and Adamson water meter. Contributed by Sir C. W. Siemens, 1858, and Messrs. Guest and Chrimes, 1862.

This form of inferential meter was patented by Messrs. Siemens and Adamson in 1858; it is designed to reduce the amount of water that may, in the earlier form (*see* No. 512), be passed without the indicating mechanism moving. The measurement is performed by a reaction wheel or Barker's mill, the revolutions of which are practically proportional to the velocity of the water through the orifices. This instrument has been most extensively adopted and is known as the Siemens meter.

In the sectional example shown, which is of a meter for a 1-in. pipe, the water before entering the casing passes through a strainer, it then reaches a fixed central pipe, down which it passes into the hollow centre of the revolving wheel, which in the example discharges it in six jets. The axle of the wheel is hollow below, and rests on a pivot, while the upper end is provided with a worm which gears into the counting mechanism above. The counter has two steps of worm gearing, as well as a differential arrangement involving a moving dial; there are two indicating fingers and a stationary pointer.

The reaction wheel of a much larger meter of this type is also shown.
M.167 and M.872.

514. Water meter. Presented by J. A. Müller, Esq., 1886.

This water meter is an apparatus for measuring the quantity of water passing by recording its speed. The water passes through a circular water-tight chamber, in which is a closed drum capable of revolving very freely, carrying two magnets extending across its top surface. The water, being deflected to one side of the drum, causes it to rotate by surface friction at a speed proportional to the speed of the water. In a dry chamber above the

drum are two armatures attached to a light vertical shaft. As the drum and its magnets revolve in the water chamber, the armature revolves outside, and the armature shaft gives motion to the recording mechanism. The index and dials record the quantity in litres. M.1842.

515. Tylor's rotary water meter. Lent by Messrs. J. Tylor & Sons, 1890.

This is an inferential meter, the quantity of water passed being determined by the number of revolutions made by a fan carried round by the flowing water. The fan or paddle with radial blades is placed with its axis vertical in a cylindrical casing into which the water enters by tangential openings and escapes axially. The entering water drives round the fan at a speed proportional to its velocity, and the number of revolutions is indicated by a counter at the top of the instrument connected by worm gearing with the axis of the fan. A sectional drawing shows the construction. M.2333.

516. Sporton's water meter (working). Presented by H. H. Sporton, Esq., 1901.

This is a sectional example of an inferential meter introduced by Mr. Sporton about 1885. It consists of a cylindrical casing with the usual counting mechanism above, while the water is admitted from a side pipe, fitted with a strainer, and delivered into a chamber at the bottom of the casing, from which it issues in inclined tangential jets, of circular section. These strike against the inclined vanes of a six-armed fan whose vertical axis extends upward, through a stuffing box to the counter; the water after acting on the fan passes, by an opposite side pipe, to the consumer. The specimen shown is for a pipe of 0·5 in. diam.; it has a capacity of 600 gal. per hour.

In a later form of this meter an arrangement was introduced to insure movement of the fan when only small quantities of water were passing. This consisted of a spring-loaded valve which, when the demand was so small as to cause but a slight difference of pressure between the supply pipe and the meter, remained closed, a few specially inclined holes near the periphery alone remaining open, and through these the water issued with sufficient velocity to move the fan. M.2544.

517. Helix water meter. Presented by the Leeds Meter Co., Ltd., 1913.

This is an inferential meter, designed for measuring large flows with small loss of head. It determines the flow from the revolutions of a propeller which is placed in the pipe and connected with a counter by gearing.

The meter consists of a short brass cylinder having a flange at each end, by means of which it is secured between the flanges of two adjacent pipes. The propeller is of celluloid, and is nearly as large in diameter as the cylinder; it is mounted on a horizontal axis, one end of which is supported by a spider and the other end by a grid, which also forms a guide for the water. A worm on the axis engages with a wheel on a vertical shaft, which transmits the motion to a counter housed in an upward extension of the cylinder. The meter is constructed so as to be easily taken to pieces. The example shown is for a pipe 3 in. diam., and its counter records up to 100,000,000 gal. These meters are made in various sizes from 2 in. to 30 in. diam. M.4179.

518. Rotary water meter. Presented by the Leeds Meter Co., Ltd., 1909.

This is an inferential meter, in which the quantity of water passing is indicated by the number of revolutions made by a fan carried round by the flowing water.

In this specimen the fan has radial blades, is made of celluloid, and is mounted on an agate pivot; it revolves in a vertical chamber, and the water, after passing through a strainer, flows tangentially past it in a single stream. The speed is regulated by four adjustable vanes placed above the wheel, which act by producing eddies. The fan bearings are protected from the wearing action of the water by metal shells surrounding them. The meter has a wet dial, that is, all its mechanism works in the water; a stuffing box on the spindle, with its attendant friction, is obviated, thus making the meter more sensitive. The dial is of the transparent type patented by Mr. C. Meinecke in 1903. This consists of a thick glass plate, having the dial circles and figures formed on its lower surface; these are covered with white enamel, in which small circular openings are left, and through these the pointers below are seen. The figures on a dial of this form cannot be obscured by dirt in the water.

The example shown is for a 0·75 in. pipe, and the counter registers up to 10,000,000 gal. before repeating. M.3590.

519. Venturi meter and manometer. Presented by Messrs. George Kent, Ltd., 1910.

This inferential water meter was invented by Mr. C. Herschel in 1881 ; it consists simply of a contracted or Venturi tube forming part of the pipe through which the water is flowing. It depends for its action on the truth of Bernoulli's theorem which shows that the total energy in a steady stream of fluid is constant, so that if at any section, such as the throat of the tube, the velocity increases, then the pressure must decrease, and the difference in pressure at the entrance and throat will be proportional to the square of the velocity, which can be readily calculated. Owing to viscosity the actual velocity is somewhat less, but in large meters it reaches 99·5 per cent. of the calculated value; this proportion is, however, lower in small meters and varies considerably with the velocity, so that they have to be carefully calibrated. The meter is very simple and has no working parts in contact with the water ; it has a large range of registration, and is the most satisfactory meter for measuring large quantities of water such as are dealt with at waterworks. It may be used for any other fluid, such as compressed air.

The small example shown is built up of three castings bolted together, hand-holes being provided for inspection. The inlet end converges sharply to the throat, but the outlet expands more gradually. At the entrance and throat the tube is surrounded by annular chambers, which communicate with the interior of the tube by four small holes; the pressure-gauge pipes are attached to these chambers. The difference of pressure at the two points is indicated by a single tube mercurial manometer of the form patented by Messrs. W. G. Kent and J. L. Hodgson in 1910. This consists of a cast iron reservoir of large sectional area connected with a vertical gauge glass ; a pipe from the meter entrance allows the upstream pressure to act upon the surface of the mercury in the reservoir, while the upper end of the glass tube is similarly connected with the throat. Controlling, equalising, and air cocks are fitted. A scale with a pointer is mounted close beside the gauge glass and reads the pressure difference in inches, allowance being made on it for the slight fall of the mercury in the reservoir.

The meter shown is for a pipe 3 in. diam., and would be used for hot water or boiler feed measurement. It has a throat ratio of 1 : 12, a minimum registration of 260 gal. per hour, and a maximum registration of 3,400 gal., the corresponding velocities being 0·24 and 3·1 ft. per sec.; the loss of head in the meter at the maximum flow is 3·5 ft. For general waterworks purposes the meters are much larger; the largest yet made are 10 ft. diam., and are capable of measuring 14,000,000 gal. per hour. With these meters the recording manometers shown on the adjacent drawing are used. The first shows, by a diagram, the rate of flow at any instant, the area of the diagram giving the total quantity passed ; the second records, by a counter, the total quantity, as well as gives the rate diagram; and the third gives the counter record of quantity only. M.3791.

Gas Meters.

520. Wet gas meter (working). Lent by Messrs. James Milne & Son, Ltd., 1905.

This is a wet meter of an early type, made about the year 1827 by Messrs. James Milne & Son.

The meter consists of a cast iron case, partly filled with water, containing a horizontal measuring drum capable of rotating on pivots. The drum is divided into four chambers by partitions set obliquely so that they cut the water, thus decreasing the resistance and rendering the motion more uniform. Each chamber is provided with an inlet and an outlet formed by extended passages which bring these openings diametrically opposite one another, thus when one inlet is open to gas the corresponding outlet is sealed by the water. The partitions stop short of the axis, allowing free passage of the water from one chamber to the other, but no gas can pass. The gas enters the meter through an axial pipe which acts as a support for one pivot of the drum, and passes into the upper part of a cylindrical chamber, forming an extension of the drum into which the gas inlets open. It then passes into those inlets which are above the surface of the water and exerts an unbalanced pressure, causing the drum to revolve until the outlets at the other end are raised above the water, when the gas is discharged into the casing and thence to the service pipe. This form of drum is attributed to Samuel Crosley, and it is, with slight modification in construction, that generally adopted in meters of this class. The volume of gas passed is measured by the number of times the chambers are filled, as registered by a counter driven by the drum. The height of the water is limited by the turned-up end of the gas inlet inside the drum to which an overflow pipe is fitted, fresh water being added through a pipe and funnel.

The top half of the casing has been replaced by a glass cover; lines are painted on the drum to indicate the chambers and passages. M.3382.

521. Wet gas meter. Presented by Messrs. Bischoff, Brown & Co., 1862.

This meter was patented in 1858 by Mr. S. Clegg, one of the pioneers of gas lighting, who in 1807 introduced the first wet gas meter.

The exterior case, of which a portion has been removed, is partially filled with water and contains a horizontal drum, capable of rotation and provided with five external spiral chambers, the small ends of which open into it and the large ones outside. The gas enters the meter by the vertical pipe seen and, after passing through a non-return valve, reaches the interior of the drum, whence it flows into one of the spiral chambers and so exerts an unbalanced pressure which causes that chamber to rise out of the water till its inner end is again closed by immersion. The next chamber then acts in rotating the drum, and the gas in the former one is discharged above the surface of the water and thence to the service pipe, the volume of gas passed being measured by the number of times the chambers are filled, as registered by a counter driven by the drum. As it is essential for accurate measurements that the immersion of the drum should be constant, its bearings are in this meter carried in a swinging frame controlled by a bell float. M.889.

522. Wet gas meters. Contributed by Messrs. W. and B. Cowan, 1873.

These embody arrangements patented in 1858–63 by Messrs. Esson and Cowan, for insuring constancy in the level of the water in which the rotating measuring drum is immersed, and also for preventing the passage of gas should the water be withdrawn.

The outer case, containing the drum, has attached to its front a rectangular chamber provided with a regulating valve and a vertical diaphragm.

The gas enters a compartment serving as a saturating chamber before passing to the interior of the measuring drum, to be registered as it causes the drum to revolve, and there is a regulating valve connected with a hollow metallic float which closes it should the water in the meter get too low; for the purpose of further maintaining the correct immersion a reserve supply of water is contained in an additional chamber within the casing.

In one example there is a notched overflow pipe from the drum chamber into a waste chamber below; a fitting is also shown for adding to a meter, which will close the outlet pipe by a water seal, should the apparatus be placed out of level. M.858, B, C, & D.

523. Wet gas meter. Contributed by W. H. Moran, Esq., 1862.

This meter, patented in 1861 by Mr. Moran, chiefly differs from others of its class in the device for maintaining the water level; this consists in the addition to the axle of the rotating measuring drum, of a disc with projections acting on a scoop which bails water from a reservoir into the drum chamber, thus maintaining it at the level of an overflow notch. M.728.

524. Dry gas meters (one working). Lent by Messrs. G. Glover & Co., 1887.

Gas meters of the bellows class, containing no water, are a more recent invention than wet ones, having been first introduced in 1820 by Mr. John Malam.

In the example shown, which has glass sides, the upper compartment is that into which the gas enters; thence it passes through ports, alternately opened and closed by two slide valves, down into the two circular measuring bellows which are attached to a central partition dividing the lower portion of the casing into two compartments. When gas is inflating one of the bellows, it is also entering the opposite compartment and so collapsing the other bellows from which it passes by the exhaust port of its slide valve into the service pipe; at the same time, gas from outside the bellows which are being inflated is, by the other slide valve, also passing into the service pipe. Uniformity of stroke is secured by connecting the pistons with a crankpin, from which mechanism the slide valves and the counting apparatus are driven. Each of the bellows is double-acting, and the whole arrangement resembles a pair of oppositely inclined diagonal steam cylinders acting on a single crank, the revolutions of which are registered as a measurement of the amount of fluid passed. The examples shown have improvements patented by Mr. Glover in 1863, including the addition of a pawl which prevents the meter being worked in a wrong direction. M.1860-1.

525. Dry gas meters (one working). Contributed by Messrs. W. and B. Cowan, 1873 and 1907.

These contain improvements patented in 1870, but the general construction is similar to that in the preceding example. The leather of each bellows is secured at its inner circumference to its piston, while the outer circumference is held by a fixed diaphragm having a corresponding hole in it, so that each piston can pass through its diaphragm, thus lengthening its stroke; between these two diaphragms is a partition completely dividing the bellows chambers.

In the working of dry meters the non-oxidising properties of illuminating gas prevent the destruction of the prepared leather, and for this reason these meters are usually kept full of gas after being tested. M.858 and M.858A.

526. Experimental wet gas meter. Received 1900.

This meter is constructed to show the rate of consumption, as well as the volume of gas which has been consumed. The quantity of gas passed is

measured by the rotation of a four-chambered drum partly immersed in water, and there is an arrangement for preserving the water level similar to that in No. 522.

Above the drum is a clock, the long hand of which revolves once a minute round a large dial fitted with another hand worked by the drum and therefore registering the amount of gas passing. Two smaller dials show time in minutes and volume in fractions of a cub. ft. M.3133.

527. Prepayment gas meter. Presented by Messrs. Sawer and Purves, 1897.

This is a dry meter fitted with an arrangement patented by Messrs. Sawer and Purves in 1891–94, by which the quantity of gas delivered by the meter is determined by the number of pennies previously placed in the slot. It is thus a measuring machine that delivers gas equivalent to the money received, while also acting as an ordinary recording meter.

The example is fitted with glass panels through which the mechanism is visible. Below is the usual double bellows of a dry meter, while above is the mechanism that shuts off the gas after the amount paid for has been delivered; on the left side is a locked box in which the coins received collect. A projecting handle is connected with a grooved drum inside; when a penny-piece is placed in the payment slot above, the coin drops into the groove, but projects from the face of the drum so as to act as a driving pawl, until a half-revolution has been performed when the coin tumbles into a locked box, the coin thus acting as the driving pawl for power transmitted from the external handle. Each half-revolution rotates a quick-pitched screw, on which is a nut that turns on the gas; this nut is formed as a spur wheel and is geared to the mechanism, so that as the gas passes the nut is rotated and thus slowly moved backward until it neutralises the motion given by the screw and again turns off the gas. If several coins are inserted the resulting motion of the screw is greater, and consequently the meter works longer before this motion is again neutralised. The arrangement of differential gear resembles that used in some forms of steam steering gear. The amount of gas paid for, but still unconsumed, is shown by an index attached to the nut. M.3004.

528. Wet gas meter. Lent by George Wilson, Esq., 1905.

This is a wet meter of the ordinary type, fitted with appliances for preventing fraud by disturbing the water level.

It consists of a cylindrical case containing a measuring drum partly immersed in water. The drum is of the form designed by Samuel Crosley about 1821, and afterwards slightly improved in construction; it has oblique internal radial partitions stopping short of the axis, and forming, with the end plates, four chambers. The inlets are at the front end under a cover and the outlets at the back, placed about 180 deg. behind them, so that each outlet rises from the water just after the corresponding inlet has been closed. The gas enters those measuring chambers whose inlets are above the surface of the water and exerts an unbalanced pressure which causes the drum to rotate until the outlets are raised above the water, when the gas is discharged to the service pipe. To the front of the case is attached a rectangular chamber communicating with it below the water level, and the gas enters the meter at the top of this chamber through a valve which is attached to a float; when the water level falls, by evaporation or otherwise, beyond a certain amount, the valve closes and cuts off the gas. More water must then be added through the guarded orifice provided, the correct height being fixed by an overflow pipe through which any excess passes into the waste box below, whence it may be drawn by a water-sealed pipe. The gas passes from the front chamber by a vertical pipe having its mouth above the water and a branch leading through a water-sealed orifice to the space under the drum cover. The motion of the drum is transmitted, by worm gearing and a vertical shaft, to the counting mechanism on the top of the front chamber.

The meter has a capacity of 30 cub. ft. per hour when making 2 rev. per min. This specimen is fitted with glass panels to show the construction. M.3394.

Measurement of Mass.

529. Coin balance. Received 1907.

Scales or balances of the equal-armed type are of unknown antiquity. The example shown has hanging scale pans, and has steel knife edges in a steel beam with Dutch ends, and brass pans, suspended by a plaited silk cord.

It is intended for the purpose of weighing gold coins. The third great re-coinage of gold in England took place in 1772–4, and of the two sets of brass weights shown one gives the lowest legal tender for coins minted prior to January 1st, 1772, and the other subsequent to that date. The weights are for guineas, half guineas, and quarter guineas; the last-named pieces were first coined in the reign of George I., and they were again coined in that of George III., but were soon discontinued on account of their small size; one-third guinea pieces were also coined. M.3481.

530. Guinea balance. Made by A. Wilkinson. Received 1905.

This is a form of equal-armed balance for weighing guineas or half guineas, one by one, and giving the value of the excess or deficiency directly in pence; it must have been made anterior to 1817, when the guinea ceased to be coined.

The balance is of the same general construction as the one beside it (No. 531), but the weight is attached directly to the scale beam by a pin so that it can be turned over. In one position it balances the weight of a guinea and in the other that of half a guinea. The beam on the other side of the fulcrum is fitted with a rider and is graduated so that the deficiency in weight can be read directly in pence up to 12 and the excess in farthings up to 5. The knife edges are triangular in shape on bearings of hardened steel. Printed instructions are pasted inside the case. M.3391.

531. Coin balance. Presented by John Dickinson, Esq., 1905.

This is for weighing gold in single coins; it is by the same maker as the one beside it (No. 530) and dates probably from the beginning of the 19th century. As business was carried on in those days principally by cash payments it was convenient to have a balance in a portable form. The balance has a scale beam with two pans; the one for carrying the different weights (now missing) has a support which is required when no coin is on the opposite pan; the stand for the beam is incorporated with the hinge of the mahogany case so as to follow the lid when being closed, care being taken to fold back the scale pans on the beam. M.3392.

532. Coin balance. Presented by H. R. H. Southam, Esq., 1905.

This is a portable folding balance closely resembling No. 530, but in this case there are spaces for the loose weights, of which there have been five, but only three are left; these are for the guinea, the sovereign and the half sovereign, so that the balance must date subsequently to 1817, when the sovereign was first coined. The slotted hole probably contained a gauge for giving the correct thickness and diameter of the coins. M.3401.

533. Coin-sorting machine. (Scale 2 : 1.) Received 1883.

This is an enlarged model, simplified in detail, of the automatic balance employed in the Royal Mint for separating coins by weight into three classes: light, standard, or heavy. The machine, as originally patented in 1842 by William Cotton, Governor of the Bank of England, and there used, was only

designed for rejecting coins below the legal standard. When the machine was adopted at the Royal Mint in 1851, Mr. J. M. Napier, who had made the earlier machine, introduced improvements with the object of rejecting all those coins which were above and below a narrow margin of weight known as the "remedy," *i.e.* the limits within which the Master of the Mint is obliged to work (*cf.* 33 Vict. c. 10).

In the early form here shown, all the motions of the machine are derived from cams on three shafts geared together equally, the middle one being driven; in the form at present used all the cams are grouped on one shaft. The power is obtained through a gut band and slipping clutch (not shown).

The coins are fed by a shoot (not shown), whence they are pushed one by one by a slide on to the pan of an equal armed balance with steel knife edges. The rod to which the pan is fixed is being steadied meanwhile by a pair of lazy-tongs or forceps; further rotation releases these, and a beam near the floor level is brought against loops in the scale-pan rods to bring the balance level before weighing. The counterpoise, which is in weight equal to the lightest coin permissible, hangs in a stirrup, below which are V-shaped supports to pick up a wire of the weight of the "remedy" should the coin weigh the pan down sufficiently. When the balance has taken up its position, the forceps come into action to hold the scale-pan rod, while a finger is allowed to drop upon a loop in this rod, and so determines the level at which a balanced indicator shall stand, and consequently which of three steps on the distributing shoot will come against it. This decides which of three compartments the coin will fall into when pushed off by the next coin. The balance turns with 0·01 grain, and weighs 22 coins per minute. M.1674.

534. Coin balance. Made by Matthew Hill. Received 1908.

This balance is on the principle of the steelyard, in which the arms are unequal in length and the weights reciprocally proportional to these lengths. In the common steelyard, which dates from Roman times, the fulcrum is fixed and the balance weight slides on the longer arm; in the less usual Danish steelyard the fulcrum is movable. The balance shown is of the former type and was designed in 1775 for weighing gold coins at a time when a great re-coinage of gold had taken place (*see* No. 529).

The steelyard is supported on steel knife edges from a bent wire. The coin is held in a clip suspended from the shorter arm and is balanced by a weight sliding along the longer arm. A spring on the weight takes into a notch on the arm at a point corresponding to the weight of a guinea, a half guinea or a quarter guinea. In each case there is a second notch giving the minimum legal weight allowable. If not within these limits a slider on the short arm gives directly in pence, half-pence or farthings respectively the value of the deficiency. The box into which the balance folds serves as a support for the bent wire. M.3583.

535. Danish steelyard. Received 1909.

This is identical in principle with the Roman steelyard (*see* No. 534), but the balance weight is constant, the fulcrum being moved till equilibrium between the weight and the load is established.

This was the type which, under different names (*e.g.* "bismar" in Orkney and Shetland), was commonly employed till within recent times by the peoples of Northern Europe. It has the disadvantage that the readings become very crowded as the fulcrum is moved close to the load. The example shown is graduated to read in kilo. on the top to 10, and in lb. on the side to 40. The balance weight was probably covered with leather originally. M.3686.

536. Chondrometer. Made by Berge. Received 1908.

This is a pocket balance on the principle of the steelyard (*see* No. 534) for ascertaining the weight of a given bulk of grain, that being a rough guide as to its quality.

The steelyard is supported on knife edges on a turned brass stand. The grain to be tested is placed in a bucket and struck off level by the boxwood strickle. The bucket is hooked on to the shorter arm and the weight is slid along the longer arm until equilibrium is established; the readings are in lb. per bushel, and the instrument gives the weight from 20 to 70. M.3541.

537. Gold coin tester. Received 1910.

This is a form of unequal armed balance and gauge combined, used in shops for testing the weight and thickness of gold coins.

On the beam are two recesses or pans, each with a gauge slot, one being for sovereigns and the other for half sovereigns. The distances of the pans from the fulcrum are in the ratio 2 : 1, so that a lump cast on the other end of the beam balances either coin if in its proper pan. There is a nail-moved slider for giving the deficiency in value of a sovereign (if any) from one up to six pence. M.3717.

538. Grain-weighing machine. (Scale 1 : 4.) Presented by W. H. Baxter, Esq., 1881.

This is an automatic machine, patented by Mr. Baxter in 1869–80 for weighing brewers' malt and recording the duty payable; it was to be placed in a locked enclosure so situated that all malt, on its way to the rolls, must pass through it.

The malt is delivered, by an overhead shoot, into a cylindrical drum, carried on trunnions hanging on knife edges on a scale beam; when the drum end of the beam descends sufficiently, a lock retaining the drum is released and at the same time the supply of grain is shut off, while a wheel on the trunnion comes into gear with a pinion continuously rotated by power, so that the measuring drum is quietly emptied. It then completes its revolution and rises to the charging position; in so doing turning on the supply of grain and moving a counting apparatus, the dials of which indicate the amount of the tax to be paid in £ s. d.

The cup elevator, or "Jacob's ladder," shown was added to facilitate experiments with the model. M.1508

539. Early counter weighing machine. Received 1903.

The application of compound levers, as in the modern platform weighing machine, appears to have been first made about 1743 by John Wyatt at Birmingham.

The machine shown is of uncertain date, but is believed to have been made in the 18th century and it somewhat resembles Wyatt's arrangement. The scale pan is in the form of a platform, giving unlimited vertical and lateral space for the object being weighed; beneath it at one end is a steelyard with its fulcrum extended as a shaft, so that the knife edges at its ends are sufficiently separated to give lateral stability. Above the steelyard is an equal-armed balance beam by which some of the weight of the platform is transmitted, as an upward pull, to one side of the steelyard, while the remainder of the weight acts directly downward upon the steelyard by two knife edges at the same leverage on the other side of the fulcrum. As the platform is supported on three edges which have equal vertical motions, it is steady and remains horizontal.

The long arm of the steelyard is graduated by side pegs into eight divisions, each equal to the short arm of the lever, so that a pound weight hung on these will weigh from 1 up to 8 lb. (*i.e.* a butcher's stone) on the platform. M.3283.

540. Indicating weighing machine. Lent by Messrs. W. & T. Avery, Ltd., 1914.

This is a pendulum weighing machine of the form patented by Mr. A. De Vilbiss and the Toledo Scale Co., U.S.A., between 1899 and 1909. In it

the object to be weighed is placed on a scale pan and is balanced by a pendulous weight which alters its angular position, while a pointer moving over a scale indicates the weight. With a machine of this kind weighing is performed quickly and accurately, and no loose weights are required.

The mechanism consists of a lever pivoted at one end, while the other end is hung on a steel tape fixed to and passing round an adjustable pivoted quadrant or horsehead, to which is attached an arm carrying a weight at its lower end; a pointer is also attached to the quadrant. The scale pan bears on the lever at an intermediate point, and it is guided by a parallel motion. At the zero position the pendulum is vertical, but a load placed on the pan turns the pendulum towards the horizontal position so that its effective leverage is increased. An adjustable dashpot is placed below the lever to damp out vibration, and agate bearings are used throughout. All the working parts are enclosed, and rubber buffers are provided to limit the swing of the pendulum.

The example shown is intended for the confectionery trade and has a capacity of 1 lb.; the indicator is graduated to quarter ounces. Larger machines of this type have cylindrical indicators and computing scales by which the weight and price can be read off at once. Inv. 1914—685.

541. Mancur's spring balance. Presented by H. W. Dickinson, Esq., 1905.

This is perhaps the simplest application of the elastic extension of a spring to the purpose of weighing. A plate spring of tapering section is bent to an elliptical form with the ends overlapping; a pointer hinged to one end passes through a slot in the other. When a weight is suspended from the spring the ends tend to separate, causing the pointer to move over a graduated scale which is fixed to the neutral part of the spring. By adopting two different positions for the suspending hooks a large range can be obtained, the reading being from zero to 32 lb. rising by 1 lb. on one side of the scale, and from 20 lb. to 300 lb. rising by 30 lb. with further sub-division to 5 lb. on the other side.

The balance is intended for household use, but as the accuracy is only about 1 in 100 it has been largely displaced by other forms in which a helical spring is used. M.3398.

542. Duckham's hydrostatic weighing machine. Lent by the East Ferry Road Engineering Works Co., 1891.

This machine, patented in 1869 by Mr. F. E. Duckham, consists of a cylinder carried by an iron strap by which it can be suspended from a crane-hook. Within the cylinder is a leather-packed piston, the rod of which passes through a leather collar at the bottom of the cylinder, and is provided with a hook from which the mass to be weighed is suspended. The cylinder is full of oil, and communicates with a gauge attached to its front, by which the pressure on the oil is measured, the dial being so divided as to indicate directly the weight lifted. By slightly rotating the suspended load the friction of the packing is practically eliminated. The example is for dealing with weights up to one ton. M.2376.

Measurement of Velocity.

543. Speed indicator and recorder for railway trains. Contributed by Mrs. W. A. Brown, 1891.

This machine was patented in 1863 by Mr. W. A. Brown, but to some extent the invention was anticipated by an instrument devised about 1846 by Mr. W. Ricardo. Its object is to obtain a diagram of the speeds of a train throughout its journey, and also particulars of the various stoppages. This

is drawn upon a ribbon of metallic paper, which is passed between rollers at a constant rate by clockwork, whilst a marker is moved across it at a speed proportional to that of the train. In this way a continuous time-distance line is drawn, which is parallel to the direction of motion of the paper when the train is at rest, and inclined when the train is moving; the tangent of the angle of inclination being proportional to the speed.

In the instrument shown the motion of one of the train wheels is communicated to the pulley at the side of the box containing the apparatus. This pulley makes about 220 rev. for every mile travelled, and communicates motion to a traversing screw carrying a nut to which the marker is attached; the marker moves through 1 in. for every 2·25 miles travelled, and the paper advances at the rate of 1 in. in 10 minutes. At the right-hand side of the instrument is a reversing clutch by which the movement of the pencil is automatically and rapidly reversed before the marker reaches the edge of the paper, so that a diagram of indefinite length can be taken.

In the diagram appended, which records a journey of about 78 miles on the London, Chatham and Dover line from Victoria Station to Dover Harbour, the intervals between the transverse lines correspond to minutes. The speed of the train at any instant, which is indicated by the slope of the recording line, can be read directly by means of a specially graduated protractor. It will be seen that the greatest speed was obtained between Selling (S L) and Canterbury (C Y), and was 46 miles per hour. Where the train was at rest the recording line is perpendicular to the transverse lines, the lengths of such parts giving the durations of the stoppages; thus at Clapham and Brixton the train stopped for 0·5 and 1 min. respectively, whilst at Herne Hill the direction of slope of the line is reversed for a short distance, indicating that the train was backed about 100 yd., just after entering the station. M.2398.

544. Speed indicator. Lent by H. Faija, Esq., 1876.

This "motometer," patented by Mr. A. Barlow in 1875, is designed to show on a dial the speed of a revolving shaft, in revolutions per min.; it differs from most appliances of the class in that it is a combination of a clock and a counter, and gives a result that has been averaged over a definite interval.

The speed is shown by a pointer, carried loosely on a sleeve, which forms part of a clutch and is driven from a clock train at the rate of one turn per min. The clutch is released momentarily by ratchet gearing, driven from the shaft whose speed is to be observed, and so arranged that the clockwork steadily moves the pointer sleeve while the shaft makes 200 rev. and then releases it, so that the distance thus travelled by the pointer is greater the lower the speed of the shaft. The pointer and sleeves are, by springs, continually tending to fly back to the starting position when released, and the pointer is also fitted with a brake which retains it over its last reading till it is momentarily released, to permit of its moving into the fresh position should the speed have altered during the last interval.

In another and more obvious form of the instrument, the shaft drives the clutch and pointer, while the clockwork releases the clutch at intervals of one minute, the pointer being, however, retained at its last reading as above until the end of the fresh minute. M.1427.

545. Speed recorder for trains. Lent by Messrs. Elliott Bros., 1862.

This apparatus is intended for recording on paper the speed at which a train is running. Motion taken from one of the axles would cause the vertical spindle to revolve, tending to carry the fan with it; the resistance of the air would cause the fan to mount the thread of the screw, more or less, according to the speed. The rise and fall of the fan, communicated to a pencil bearing against the paper on the revolving drum, would record the variations in speed. Hick's engine governor of 1840 (*see* No. 295) has a similar mechanism. M.343.

546. Speed indicator. Lent by J. Ramsbottom, Esq., 1890.

This instrument, known as Ramsbottom's velocimeter, was devised in 1860 for indicating the speeds of locomotives while experimenting with the inventor's arrangement for supplying tenders with water while running (*see* No. 257).

The closed glass tube half filled with oil revolves on a vertical axis and was driven by a band from a sheave on the trailing axle of the locomotive. The depressed centre of the surface of the rotating oil when read by the graduated scale at the side of the tube, gives the speed of the engine in miles per hour; the amount of depression varies as the square of the speed. A sectional drawing is shown. M.2310.

547. Drawing of Stroudley's speed indicator (Scale 1 : 3). Prepared 1904. Centrifugal pump. Lent by Messrs. Dewrance & Co., 1888.

This indicator, patented by Mr. W. Stroudley in 1879, consists of a tank containing water, from the bottom of which a tube connects it with the simple centrifugal pump with eccentric casing shown, which is actuated by a suitable working part of the engine. The rotation of the pump-wheel causes the water to rise in the glass tube in front of the graduated scale. For indicating the speed of locomotives, the motion is taken from one of the non-driven axles and the apparatus is so graduated that the scale indicates miles per hour. The scale can be adjusted so as to compensate for any variation in the amount of water in the tank of the pump. Should the water rise beyond the top of the glass tube, it flows back into the tank by the tube at the back of of the graduated scale. M.1922 and M.1937.

548. Hedge's speed indicator. Received 1890.

This instrument, by Mr. K. Hedges, closely resembles the velocimeter of Mr. Ramsbottom, No. 546, but is an improvement in that the depression of the parabolic cavity is directly proportional to the speed, so that the graduations of the scale are uniform and the range of the instrument is greatly increased. The difference is due to the top of the tube being closed by a flat cover and a much larger proportion of the tube being filled with liquid. When in use the diameter of the parabolic air cavity at the top is less than the diameter of the tube, and varies with the speed in such a manner that the vertex of the paraboloid sinks proportionately with the increase in the speed. A sliding sighting bar is attached to the case to assist in accurately determining the position of the vertex, the reading being taken on the fixed scale. M.2314.

549. Speed indicator. Lent by Messrs. D. Napier & Son, 1892.

In this instrument the speed is shown by the rise of a column of mercury in a fixed glass tube, the lower extremity of which is in communication with the circumference of a closed rotating cup of mercury, the centrifugal pressure of which is thus indicated.

The fixed support of the glass tube forms the framing of the machine and carries the bearings of the rotating cup. The lower bearing is a footstep, and the upper one is formed by a boss projecting downwards into the mercury cup. The interior of this boss communicates with the glass tube, and also with a fixed tubular arm which reaches to the circumference of the rotating cup. The cup is about half filled with mercury, the rotation of which is insured by vanes provided inside the cup. A set of baffle rings is introduced to prevent the splashing out of the mercury round the upper bearing. For transport a screw on the footstep enables the top of the mercury cup to be forced against a leather washer attached to the framing, thus completely

closing the receptacle. The scale is graduated experimentally, but the heights increase nearly as the square of the speed. A line on an ivory float on the top of the mercury column enables the scale to be easily read. A sectional drawing is shown on the label. M.2462.

550. Tachometer. Made by Messrs. Buss, Sombart & Co. Received 1909.

This is an instrument for indicating the speed of a rotating shaft, patented by the makers in 1877. The mechanism consists of a centrifugal governor connected, by levers and gearing, with a pointer which moves over a graduated dial. The governor is of the special cosine form patented by Mr. E. Buss in 1876; it is placed with its axis horizontal, and its sliding sleeve is controlled by a weighted lever, outside the casing, which gives a load increasing with the displacement. The governor consists of two semi-cylindrical weights, pivoted by their axes at points some distance from the axis of the shaft. Arms on these weights are directly connected with swivelling bolts attached to the head of a sleeve that passes through the casing, and bears upon a guide plate, which is in contact with rollers mounted on the controlling lever. This form of governor possesses the feature that the pressure on the sleeve is dependent only upon the angular velocity of the shaft, and not upon the positions of the revolving parts, so that the pointer will always indicate correctly in spite of any wear that may take place; it is also very stable, a large range of speed being covered between its extreme positions. The driving shaft is carried in a long bearing, upon the outside of which the driving pulley runs, so that no belt pressure is transmitted to the shaft. The dial is mounted on the top of the casing. The axis of the controlling lever carries another lever which is connected, by a vertical rod, with a shorter lever placed upon the axis of a toothed sector behind the dial, and the sector gears with a pinion on the axis of the pointer; by this arrangement the divisions on the dial are made more uniform. M.3699.

551. Speed indicator. Lent by Messrs. Elliott Bros., 1888.

This form of speed of revolution indicator was patented in 1881 by Mr. D. Young.

It consists of a small centrifugal governor, loaded by a helical spring and enclosed in a case. When the spring is compressed owing to the centrifugal tendency of the governor balls, the speed of rotation is indicated in revolutions per minute by a finger connected with the spring by levers and toothed gearing, by which it is moved over a suitably graduated dial. M.1889.

552. Tachometer. Received 1909.

This is an instrument for indicating the speed of a rotating shaft, patented by Dr. T. Horn in 1886. It depends for its action upon the deflection of a needle by the induced electric currents produced by the rotation of a copper drum in a magnetic field, these deflections depending upon the speed of rotation.

The instrument consists of a casing containing a permanent horseshoe magnet, which has a copper drum mounted between its poles, and rotated by a pulley outside the case. Inside the drum a soft iron armature is placed, mounted on pivots, and having a toothed sector attached, which gears with a pinion fixed on the axis of a moving hand that indicates on a dial the speed in revs. per min. The instrument is unaffected by variations in the strength of the magnet. M.3700.

553. Recording speed indicator. Presented by the Cowey Engineering Co., Ltd., 1910.

This instrument, patented by Mr. L. E. Cowey in 1904, indicates the speed at which a vehicle is travelling at any instant, and shows a record of the

speed attained over the last half-mile; it also gives the total mileage covered and the trip mileage.

The indicating mechanism consists of a toothed pawl, driven by a crank rotated through a flexible shaft from the wheels of the car, which gives intermittent impulses to the toothed rim of a heavy balance wheel, whose motion is controlled by a spring acting on a chain attached to its axle. The greater the speed at which the vehicle travels the more numerous will be the impulses given to the balance wheel, with the result that it will be deflected through a greater angle. The balance wheel is connected with the indicating pointer by gearing and a coupling which has considerable play, so that the needle, which is held by friction, remains steady. The scale occupies nearly the complete circumference of the dial and reads up to 40 m.p.h.

The speed-recording mechanism consists of a number of pivoted arms, whose ends act as pointers, moving in radial slots cut in a dial plate which is marked with circles corresponding to increments of speed of 5 m.p.h., up to 40 m.p.h. The dial and the plate behind it to which the pointers are pivoted are slowly rotated, and guides, which are set at a varying radial distance by the speed-indicating mechanism, cause the pointers to move outward to the requisite distance, corresponding to the speed at the moment, as they pass the lowest point of the dial. They are returned to zero by fixed guides after having completed the circuit.

An ordinary cyclometer is fixed near the bottom of the casing, and is driven from the main shaft; it reads up to 100,000 miles. The trip mileage recorder is mounted above and is driven by worm gearing from the indicator crank disc. It has a circular dial and two hands, one of which reads tens of miles and the other miles and furlongs; it reads up to 100 miles and the hands can be set back to zero at any time. The instrument is driven from one of the front wheel hubs by bevel gearing and a flexible chain enclosed in a helical steel coil and a flexible brass tube. Driving from the rear wheel is unreliable owing to the slipping that takes place. M.3747.

554. Magnetic speedometer. Lent by the "A.T." Speedometer Co., Ltd., 1913.

This is an example of the speed indicator and mileage recorder for motor vehicles patented by Messrs. G. and C. Ihle in 1905 and 1908.

In it a light aluminium armature, to which the indicating pointer is attached, is placed in the field of a permanent magnet mounted on a shaft. When the magnet is rotated, by means of a flexible shaft connected with one of the road wheels, the armature is drawn round against the action of a light spiral spring. The armature is a cylindrical shell with one pole of the magnet fitting within it while the other pole surrounds it, so that all the lines of force pass radially across the armature. The scale occupies nearly the whole circumference of the dial and is regular and open. The magnets are fitted within a brass shell, the outside of which is screwed and serves to drive two worm wheels, one of which drives a mileage counter, and the other a trip counter, the figures of which can be set rapidly to zero. The instrument shown indicates speeds from 0 to 40 miles an hour; the total distance counter records up to 10,000 miles, and the trip counter up to 1,000 miles. M.4270

555. Speedometer (working). Lent by Messrs. Bowden Wire, Ltd., 1911.

This is an example of the speed indicator, for motor-cars, etc., patented by Messrs. C. Spratt and F. J. Shenton, in 1908.

It is of the centrifugal type, and consists of a vertical spindle having at its upper end a conical disc with five radial slots, in each of which a steel ball fits loosely; the cone is surrounded by a loose cup, running on ball bearings, and having a curved inner surface up which the balls run, as they move outward when the spindle is rotated. The cup being loose, wear over its

whole surface is equalised. A flat plate rests on top of the balls, and a rod projecting upward from its centre has a rack cut upon it that engages directly with a pinion on a horizontal spindle which carries the indicating pointer at its end. A three-armed spring presses the plate down on the balls. The pointer is balanced, and backlash between the rack and pinion is prevented by a light spiral spring on the spindle; it moves over a very open and fairly uniform scale, reading from 5 to 50 miles an hour. The mechanism is completely enclosed, and a cyclometer, recording up to 10,000 miles and driven by a worm on the spindle, is arranged in the lower part of the casing. A lubricator is provided at the top. The spindle is usually driven, through a flexible shaft, from one of the car wheels, by an adjustable friction wheel drive, but a gear drive can be used if required. M.3984.

556. "Watford" centrifugal speedometer. Presented by Messrs. Nicole, Nielsen & Co., Ltd., 1913.

This is an example of the speed indicator and mileage recorder, for motor vehicles, patented by Messrs. A. E. Rutherford and R. B. North in 1909–10.

The governor is in the form of a heavy ring pivoted about a diameter on the driving shaft. When revolved, this ring tends to set itself normal to the shaft, and in doing so draws down a sleeve, with which it is connected by a link, against the action of a helical spring. A slot on the sleeve engages with a pin projecting from the face of a pivoted quadrant the circular edge of which is provided with teeth that engage with a pinion fixed on the spindle carrying the indicating pointer. This arrangement allows the pointer to move round nearly the whole circumference of the dial with a small movement of the sleeve. Speeds up to 60 miles an hour are indicated. The main shaft drives, through spur and worm gearing, a mileage counter recording up to 100 miles. The figures of the latter can be reset quickly to zero, by a number of strokes of a projecting plunger, the driving mechanism being arranged so that the dials are free from it, except at the moment when they are being rotated. Inv. 1913–46.

557. Magnetic speedometer. Lent by the Cooper-Stewart Engineering Co., Ltd., 1911.

This is an example of the motor car speed indicator and cyclometer, patented by Mr. J. K. Stewart in 1910. In it there is an annular permanent magnet, slit through at one point, mounted on ball-bearings and rotated by bevel gearing from a shaft projecting through the bottom of the enclosing casing. The magnet is surrounded by a sheet steel cylinder rotating with it and leaving a narrow channel around the magnet into which projects, without touching, the cylindrical flange of a light non-magnetic disc mounted on a spindle to which an index finger is attached. When the magnet is rotated, the disc is drawn round, against the resistance of a light spiral spring, through an angle proportional to the speed; the attached index moves over a very open and equally divided scale marked on the dial. The magnet is the only moving part and this rotates 400 times per mile; the instrument records very low speeds. A cyclometer is added which records the total mileage up to 100,000 and the trip mileage up to 1,000.

The instrument is driven from one of the front wheels of a car, through spur gearing, a swivel joint, and a flexible shaft. M.3945.

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558. Biram's anemometers. Made by Messrs. John Davis & Son, 1865 and 1882.

Instruments for measuring the velocity of air by the aid of a reversed windmill were first patented by Mr. B. Biram in 1842, but a somewhat similar arrangement had been proposed earlier.

The early example shown has a ten-bladed wheel 12 in. diam. built of copper, and provided with sails of oiled silk; the axle of the wheel carries a

worm actuating a three-figure counter, and the velocity is determined from the difference between the readings at the commencement and close of an interval measured by a watch.

In the later example the wheel is arranged in a cylindrical shield 4 in. diam., and has aluminium blades, while the counter is secured above it, the connection between them being made by worm gear and a shaft which can be disengaged at will, so that the counting mechanism can be thrown into action for a minute or other interval and then released. The table and diagram for the correction at various speeds is attached. M.1294–5.

559. Lowne's anemometer. Made by Messrs. John Davis & Son, 1882.

This modification of the Biram anemometer is convenient in that the counter is horizontal and is directly carried by the stand on which the fan and its guard are supported. The wheel is 2·5 in. diam., and has eight aluminium vanes. The connection with the counter has the usual disengaging motion. M.1596.

560. Dickinson's anemometer. Made by J. Casartelli, Esq., 1901.

This instrument, introduced by Mr. Joseph Dickinson about 1850, determines the velocity of an air current from the deflection it causes to a swinging flap. The flap consists of a framed plate of mica, carried along its top edge between centres and fitted with a counterpoise, so that even a slight pressure on its surface shall cause an appreciable deflection. The centres are held in a square frame provided with a quadrant so graduated that the velocity of the air is indicated in feet per minute by the reading opposite the flap; a small spirit level is also attached to the framing to insure that it is vertical while an observation is being made. Like most other anemometers, it is graduated experimentally by attaching it to a long arm which is swept round horizontally at different speeds by mechanism. M.1597.

Measurement of Fluid Pressure.

561. Vacuum gauge, by James Watt. Watt Collection, 1876. Plate IX., No. 5.

This simple instrument may have been suggested to James Watt by the atmospheric engine, and was probably at the root of the invention of the steam engine indicator (*see* No. 588).

A rocking beam with segmental ends is connected by a pitch chain at one end with the piston rod of a vertical brass cylinder 1·95 in. diam. (*i.e.*, 3 sq. in. area), and at the other end with a helical spring. Connection between the condenser or other vessel, in which the degree of vacuum is to be measured, and the under side of the piston is made by means of a pipe. When a cock in the pipe is opened, the pressure of the atmosphere forces down the piston against the pull of the spring. The vacuum is indicated by a pointer fixed to the beam at its axis. This pointer is long compared with the beam and gives open readings on a scale which is graduated in inches of mercury. M.1816.

562. Pressure gauge. Presented by Messrs. Watney, Combe, Reid & Co., 1899.

This steam gauge was attached to the cylinder jacket of a rotative beam engine supplied by Messrs. Boulton, Watt & Co., in 1808, to Messrs. Reid's brewery, Clerkenwell. The boiler pressure was 5 lb. above atmosphere, and this gauge represents the arrangement in general use till about 1850, when the continual increase in pressure led to the adoption of dial gauges.

The apparatus consists of an inverted siphon pipe of wrought iron, one extremity of which was provided with a flange, for attachment to the steam jacket or to the steam pipe, while the other was fitted with a socket which supported a glass tube that protected a light rod terminating in a cork disc. The siphon was half filled with mercury, so that when the steam pressure increased, it caused the mercury to rise in the outer leg and so lift the rod within the glass tube, thus indicating the pressure, usually upon a scale placed behind the tube. The tube was closed at the top, but was so fitted as not to seal the end of the siphon. M.3075.

563. Vacuum gauge. Presented by Messrs. Watney, Combe, Reid & Co., 1899.

This gauge, for indicating the degree of exhaustion of the condenser, was fitted to the same engine as the pressure gauge No. 562, the connection with the condenser being made by a considerable length of copper pipe. From this pipe a wrought-iron extension piece, 0·375 in. external diameter, passed up through a small reservoir to the top of the closed end of a vertical barometer tube. The reservoir was open to the atmosphere, and was filled with mercury, so that as the pressure within the condenser fell the mercury was forced up the barometer tube by the atmospheric pressure. The whole instrument is constructed within an iron casting mounted on wood; near the upper end of the exposed portion of the tube is a graduated scale for reading the difference between the pressure of the atmosphere and that within the condenser; this is given in inches of mercury, the graduations being so reduced that the reservoir correction is allowed for. M.3076.

564. Bi-fluid pressure gauge. Received 1907.

As a sensitive instrument for measuring low pressure, this differential pressure gauge was adopted between 1850 and 1860 by the Rev. A. Rigg to decide certain points of dispute with reference to infringements of a patent.

It consists of two reservoirs containing water, connected at the bottom by a pipe fitted with a stop cock. An inverted U-tube is placed in communication with the reservoirs and the space above the water columns is filled with a liquid of 0·9 specific gravity through the funnel mouth at the top of the U-tube, which is then closed by a stopper. When the reservoirs are placed in connection with the pressures which are to be compared, the difference in the heights of the water columns is a measure of the difference in the pressures. The effect of the liquid in the upper part of the tube is in this case to increase the sensitiveness of the instrument in the ratio 10 : 1 as compared with that of an ordinary water gauge. The nearer the density of the liquid selected approaches to unity, *i.e.*, to the density of water, the more sensitive the instrument becomes. The area of the reservoirs is considerable compared with that of the U-tube in order that the water level in them may remain practically constant and so not affect the readings. M.3508.

565. Steam and vacuum gauge. Presented by Messrs. Mather and Platt, 1859.

This is a portion of a mercurial gauge patented in 1856 by Messrs. C. Mather and C. Millward. The scale is only 4 in. in length, but the range is up to 100 lb. pressure, a result that is due to the use of a long mercurial standpipe of much smaller diameter than that of the glass tube. Steam admitted to the top tube forces the mercury up, and then through the fine vertical standpipe that enters the tube at the bottom. Three-way cocks were introduced by which the gauge could be placed in communication with the condenser when required. M.303.

566. Siphon gauges. Presented by J. Daglish, Esq., 1868.

The two examples show water gauges used for measuring the differences in pressure involved in mine ventilation. Each consists of a U-tube partly filled with water and having one end open to the atmosphere but fitted with a contracted or protected orifice to exclude dust, while the top of the other limb is connected by a tube with the upcast shaft, or other place where the pressure is to be investigated. The difference in the level of the water in the two tubes corresponds to the difference of pressure, and is read on a boxwood scale fitting between the two tubes and adjustable, so that its zero mark can be placed at the water level in one of the tubes. In the Daglish gauge the position of the scale is adjustable by a quick-pitched screw, and a spirit level is added to insure the scale being vertical when read. M.1592–3.

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567. Pressure gauge. Presented by Messrs. Smith Bros. & Co., 1902.

As boiler pressures increased, the mercury gauge originally used became very inconvenient, owing to the height of the column required, hence locomotives were unprovided with any means of telling the steam pressure; in a few instances a form of thermometric gauge was adopted, but the usual practice was to rely upon the indications derived from the spring-loaded safety valve.

Mr. Sydney Smith, of Nottingham, was one of the earliest to produce a convenient form of mechanical pressure gauge, and this he patented in 1847, while in the same year he submitted it to George Stephenson, who at once had it tried on one of the boilers at his Tapton colliery. The gauge consisted of a diaphragm of vulcanised india-rubber held at its circumference between flanges which connected the two halves of a spherical chamber. The lower half of the chamber was in communication with the boiler, and the upper half supported a vertical dial, over which an index finger was moved by a rod, so connecting it with the centre of the diaphragm that it indicated in a greatly magnified manner the amount of bulging which the pressure was occasioning.

In 1854 Mr. Smith patented an improved form of this gauge, and the example shown, which was made about 1860 and was in use for 40 years, is of this later type. The diaphragm is still of vulcanised rubber, but it is loaded or reinforced by a close volute spring wound with such a camber that at the working pressure it is approximately flat. To the centre of the spring is secured a vertically-guided rack gearing into a pinion on the index spindle, as shown in the attached drawing. M.3256.

568. Pressure gauges. Contributed by Messrs. J. Dewrance & Co., 1862.

The form of pressure gauge shown was introduced in 1849 by Mons. E. Bourdon, who discovered the action upon which it relies while attempting to remove, by the application of internal pressure, the flattening caused in a pipe by bending it into a coil. He noticed that as the pressure was applied the pipe slightly straightened, and by fitting the free end with a pointer, found that reliable readings of the pressure were thus obtainable. This action depends on the fact that the product of the curvatures of a surface in planes at right angles is constant, so that if one radius of curvature is diminished, as by the elliptical section becoming more nearly circular, the other radius increases.

The gauge consists of a thin curved tube of elliptical section, with one end fixed in a block to which the admission pipe is attached, while the other end is free; this end is closed and connected by multiplying gear with the index. In one of the forms shown, a link from the end of the tube is

connected with a short extension of the index finger, which is pivoted near the edge of the dial. In the other, the link is connected with a pivoted lever having a toothed sector that gears with a pinion on the axis of the index, which is mounted centrally so that the scale may extend round the whole circumference of the dial. M.366.

569. Pressure gauges. Contributed by J. Inshaw, Esq., 1862.

This arrangement of pressure gauge was patented by Mr. Inshaw in 1856. One of the gauges is probably the experimental instrument and has its mechanism visible, but the other is a completed boiler fitting, closed in.

Two thin discs of sheet metal are connected at their edges so that steam or other fluid under pressure admitted into the space between the discs causes them to bulge outwards. Two curved levers pressing against the discs, communicate motion to the index by means of a rack and pinion, the bulging of both discs being utilised.

The action resembles that of the aneroid barometer, which is stated to have been first constructed by Vidi in 1847. M.365.

570. Steam and water gauge. Contributed by Messrs. Chadburn Bros., 1862.

In this gauge, patented by Mr. A. Chadburn in 1856, the pressure to be determined is measured by the amount of bulging it causes in a flexible disc of sheet metal, secured round its edge to a circular box into which the fluid is admitted. The slight movement obtained is multiplied by levers that transmit it to the index. M.836.

571. Steam gauge tester. Made by Messrs. W. McNaught & Son. Received 1913.

This is an instrument for boiler inspectors, etc., for use in checking the indications of ordinary dial gauges.

In construction it resembles the McNaught indicator (*see* No. 589). There is a cock for screwing to the steam pipe, and to this is screwed a wood lagged cylinder with a piston 0·25 sq. in. area. External to the cylinder and attached to the piston rod is a helical spring in tension. The point of attachment has an index which moves over a scale of lb. with adjustment for zero point. An extension of the piston rod has a hook for attaching weights for directly checking the accuracy of the spring (1 lb. weight equals 4lb. pressure). Inv. 1913–88.

572. Pressure gauge. Lent by Messrs. G. Salter & Co., 1887.

This modification of the Bourdon gauge was patented by Mr. G. Salter in 1879. The free end of the flattened pressure tube is provided with a pin. which fits in a radial slot very near to the centre of the index, so that the slight movement of this pin is directly magnified by the long index arm. M.1852.

573. Vacuum gauges. Lent by Messrs. Schäffer and Budenberg, 1888.

These are for showing the degree of vacuum existing in the condenser of a steam engine. One has a thin disc, which, under the pressure of the atmosphere, is bulged inwards to an extent determined by the unbalanced pressure resulting from the interior of its supporting box being in connection with the condenser. The movement is multiplied by a sector gearing into a small pinion on the index spindle, and the scale is so graduated that the reading gives the reduction of pressure in inches of mercury.

In the other a Bourdon tube is used and arranged for reading the pressure in the condenser, or the boiler pressure, provided it does not exceed 30 lb. above atmosphere. M.1900 and M.1905.

574. Steam pressure gauges. Lent by Messrs. Schäffer and Budenberg, 1888.

Two of these gauges are for steam pressures up to 300 lb. per sq. in. The red line and figures on the dial are to indicate to the stoker the maximum pressure at which the boiler is to be worked. The curved tube of flattened or elliptical cross section, of the Bourdon type, is of steel, and is partly visible through the hole in the dial.

In the third example the dial is graduated in atmospheres as well as in lb. per sq. in., the former being the method usually used on the Continent for expressing pressures. M.1902–4.

575. Hydraulic pressure gauge. Lent by Messrs. Schäffer and Budenberg, 1888.

This gauge is adapted for the high pressures employed in hydraulic machinery. The scale on the dial corresponds to tons per sq. in.; there is a second index to record the maximum pressure attained. M.1901.

576. Bourdon gauge tubes. Lent by Messrs. Schäffer and Budenberg, 1894.

These specimens illustrate the method of manufacture of two types of Bourdon tube; one is the ordinary tube for steam gauges, and the other the tube of the hydraulic gauges for very high pressure. For the steam gauge the tube is made from sheet metal with a brazed joint along what will be the inside of the coil. When making the joint the tube is somewhat circular, but is afterwards flattened to an elliptical section of about 0·625 in. by 0·187 in., which is then bent to the coil form. The hydraulic gauge is made from a short length of octagonal steel bar, bored up the centre, afterwards screwed at the ends, and greatly reduced externally so as to obtain sufficiently thin walls, while retaining the strength at the screwed extremities. The tube is then heated and bent to the form shown. M.2564.

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577. Intermittent pressure recorder. Received 1907.

This instrument was designed and made by Mr. A. Rigg in 1859. Its object was to record the pressure, once in every thousand revolutions, of a beam engine driving millstones for grinding white lead.

The engine was connected with the instrument by the shaft projecting from the front of the box, which drove a ratchet inside, operating three discs acting as cams. The cams revolved at different speeds, and when the notches cut in them coincided, a lever, held in contact with the cams by a spring, fell into the depression and opened a valve, putting the indicator into communication with the engine cylinder; the steam pipe for this connection is shown at the back of the box. The McNaught indicator (*see* No. 589), to which steam was thus admitted, then recorded, on an endless paper band, the variations in pressure for one complete revolution of the engine. The travel of the paper band round the drum was about 0·25 in. for every thousand revolutions of the engine, and as the engine made 18 rev. per min., the intervals of recording pressure were about 55 min. A portion of a record taken with this instrument in 1859–60 is shown.

The recorder was also used for testing the continuity of a water supply by taking the pressure at every thousand revolutions of a water wheel temporarily arranged to drive it. M.3507.

578. Pressure recorder. Lent by Messrs. W. H. Bailey & Co., Ltd., 1912.

This apparatus, patented in 1868 by Sir W. H. Bailey and Mr. J. L. Norton, is designed to indicate the steam or other pressure, and also to make a continuous record showing any fluctuations that may occur.

The recorder consists of a casing containing at the bottom an ordinary Bourdon pressure gauge, and at the top a clock. Between the two is placed a vertical cylinder around which is fitted a chart marked with time and pressure lines; the cylinder is rotated by the clock, and a vertically moving pen, actuated by a rack and pinion from the gauge spindle, marks on the paper a line showing the pressure at any time. The pressure lines on the chart are uniformly spaced, but are figured to agree with the gauge readings.

M.4098.

579. Recording pressure gauge. Contributed by the Seal Lock and Registering Pressure Gauge Co., Ltd., 1874.

The feature of this gauge, patented by Mr. G. A. Everett in 1873, is that, in addition to the ordinary indication of the actual pressure, it is made to indicate the number of times a given pressure has been exceeded in the working of the apparatus to which the gauge is fixed, and also the extent to which such pressure has been exceeded. The latter object is effected by a short index or pointer, which turns about the same axis as the ordinary index, and is pushed forward by it as the pressure rises, and remains as a record of the maximum attained. The number of times that a given pressure has been exceeded is recorded by three small pointers working on one axis, driven by a system of ratchet wheels. M.1334.

580. Cement testing machine. Lent by Messrs. W. & T. Avery, Ltd., 1915.

This is an improved form of the compound lever tensile testing machine originally introduced by Dr. W. Michaëlis about 1870. In it a cement briquette of standard form is held in grips and loaded by running fine shot into a bucket hung on the end of the lever.

The machine consists of a pedestal supporting the compound levers which are straight steel bars fitted with hardened steel knife-edges and bearings. The upper lever is formed as a steelyard, and carries the loading bucket at one end and a counterweight at the other end. The lower lever passes through the pedestal and carries the upper grip, while the lower grip is attached to the pedestal by a screw by means of which it is adjusted. The grips are designed to give a truly axial pull. A shot container is mounted above the bucket and its outlet pipe is fitted with a valve which allows the shot to run out at such a rate that the load is increased by 100 lb. in 12 sec., as required by the British standard specification. When the specimen breaks, the valve is automatically closed by a trigger which is struck by the falling lever. The breaking load is then obtained by hanging the bucket of shot on the short end of the steelyard, and weighing it with the weights provided, these being graduated to read the actual load on the specimen in lb. The briquettes have a cross sectional area of one sq. in. and are prepared in a gunmetal mound made in halves dowelled together and secured by a spring clamp. The combined leverage is 37·75 : 1, and the machine will give a maximum load of 1,200 lb. Inv. 1915—119.

581. Vicat needle apparatus. Lent by Messrs. W. & T. Avery, Ltd. 1915.

This appliance, designed by Mons. Vicat, is for ascertaining the commencement of hardening and time of setting, and also the correct consistency of cement.

It consists of a stand, upon which a mould containing the cement is placed, while above this is mounted a sliding spindle which terminates in a needle having a sectional area of 1 sq. mm. and a weight of 300 gm. A pointer on the spindle moves over a scale. The cement is gauged with the correct quantity of water into a stiff paste, as quickly as possible, and filled into a cylindrical mould having a glass plate bottom. This is placed on the stand and the needle gently lowered on to the cement; the commencement of the hardening is indicated when the needle fails to pass through to the glass plate. To obtain the full strength of the cement, it should be worked and used before the hardening commences.

To find the correct consistency of the cement the needle is removed and replaced by a cylinder 1 cm. diam. The mould is refilled with cement and the cylinder lowered gently on to it; the consistency is correct if the cylinder remains at a height of 6 mm. from the bottom of the mould. The correct quantity of water required in the cement may be ascertained in this manner. Inv. 1915—120.

582. Le Chatelier cement gauge. Lent by Messrs. W. & T. Avery, Ltd., 1915.

This appliance, designed by Mons. H. Le Chatelier, is for testing the soundness of cement.

It consists of a sheet brass cylindrical mould 30 mm. (1·18 in.) diam. by 30 mm. deep, split at one point and provided with a pair of brass pointers 165 mm. (6·5 in.) long. The mould is placed on a glass plate and filled with the cement to be tested; it is then covered with another glass plate, surmounted by a small weight, and immersed in cold water for 24 hours. At the end of that time the distance between the pointers is measured, and the mould placed in cold water, which is brought to the boil in 15–20 min. and kept boiling for 6 hours. After cooling, the distance between the pointers is again measured and the expansion noted. A perfectly sound cement should not expand the gauge more than 10 mm. Inv. 1915—121.

583. Thurston's oil tester. Lent by Messrs. W. H. Bailey & Co., 1894.

This is an example of the smaller class of oil tester invented by Prof. R. H. Thurston. The test spindle is carried in bearings and driven by a small pulley. The overhanging end of the spindle is formed into a journal which carries, by means of brasses, a pendulum; a screw and spring arrangement regulate the pressure upon the journal. The large figures on the face of the pendulum give the total pressure, and the small figures that on the bearing surface in lb. per sq. in. As the journal rotates it tends to carry the pendulum round with it, and the pendulum inclines until its moment, with respect to the axis, balances that of the friction between journal and bearing. The figures on the graduated arc are such that, if divided by the total pressure on the bearing, the co-efficient of friction with the oil under test is obtained.

To determine the durability of the oil it is fed in by means of a chemist's "dropper"; a certain number of drops are supplied to the bearing, and the journal is rotated until the thermometer fitted in the pendulum indicates a certain rise in temperature. The number of revolutions is recorded by the counter attached, and when compared with the results from a standard oil shows the relative durability of the sample.

The liability of the oil to "gum" is found by allowing the bearing to stand wetted with the lubricant for a certain period—12 or 24 hours. Then the journal is rotated, and the co-efficient of friction found as above, the minimum co-efficient being taken and compared with that of the standard oil. In the first and last experiments no attempt is made to measure the quantity of oil supplied to the bearing. M.2572.

584. Gunpowder tester. Received 1907.

This instrument, also known as an *éprouvette*, is for proving the strength of gunpowder. The example shown was made, probably in Birmingham, at the end of the 18th or beginning of the 19th century.

It is in the form of a flint-lock pistol with a short brass barrel; the muzzle is covered by a flat stop projecting from the edge of a graduated disc centred below the barrel. The disc is acted on by a plate spring which offers frictional resistance to its turning. The force of the explosion of the powder in the barrel caused the disc to turn and a quantitative comparison between different powders could thus be made. The indications were, however, not consistent.

M.3506.

585. India-rubber testing machine. Lent by Messrs. G. Cussons, Ltd., 1911.

This machine was designed by Prof. A. Schwartz in 1909, for determining graphically the hysteresis, or lag, of the release curve behind the extension curve, when india-rubber is alternately stretched and released. Such a test is found to disclose more valuable data than are obtained in the usual machines which determine tensile strength only.

The machine consists of a table for the recording mechanism and a vertical post for taking the test piece. The latter is held between specially designed grips, one of which is movable, and to it is attached a cord passing round a floating pulley to a helical spring. The load is applied to this pulley by a nut on a screwed rod, turned by a handle at a constant rate. To eliminate the personal element, a hydraulic cylinder, etc., may be substituted. The movement of the pulley is shared between the test piece and the spring. As the extension of the spring is proportional to the load, while that of the test piece depends on the rubber, a differential action results. To obtain a diagram, the movable grip is connected by a cord to a pencil carrier, so as to reduce its travel to half that of the specimen, while a table is moved in guides to right angles to the pencil bar by a cord connected with the spring. Both pencil and table are counter-weighted. When either a given load or a given extension is reached, the load is taken off and the rubber retracts. Curves of the form shown are obtained. From these the rate of extension or contraction, the work done in extension or contraction (the area of the loop between the curves represents the work expended in the rubber), and the permanent set are at once obtainable.

M.3935.

Measurement of Temperature.

586. Hot blast pyrometer. Received 1897.

This instrument was patented by Mr. H. Hobson in 1873, as a means for determining the temperature of the heated air supplied by a hot-blast stove to a blast furnace, and has been extensively used. As this air is frequently at a temperature of over 700 deg. C., a mercurial thermometer placed in it would be destroyed, but by this apparatus the hot air sampled is mixed with a large amount of cold air that so reduces the temperature as to bring it within the range of an ordinary thermometer, from the reading of which the higher temperature is deduced.

The instrument consists of a metal plug fitted with a wooden handle and two branches. The plug is hollow and is pressed into an orifice in the blast main, and the hot blast passing through the plug is delivered as a jet within one of the branches. This jet, by its inductive action, draws in external air from the other branch, while by a contained thermometer the temperature of the combined escaping jet is indicated.

M.2975.

587. Electrical pyrometer. Presented by Messrs. Siemens Bros. & Co., 1885.

This is a pyrometer for measuring the temperature of furnaces by means of the varying electrical resistance of platinum at different temperatures. It consists of an insulated coil of fine platinum wire, wound upon a core of fire-brick, enclosed within a sheath of iron pipe; the end of the iron sheath is in this case replaced by a glass tube to show the internal construction. Conducting wires from each end of the coil are carried through the back end of the sheath, and connected with the poles of a battery. The front end is thrust into the furnace, and allowed to remain until the heat has penetrated to the platinum coil; the strength of the electric current in the circuit varies according to the temperature to which the coil is subjected.

In the example shown the heated coil is joined in parallel with a resistance kept at a constant temperature, and a voltameter is placed in each circuit. By noting the volumes of gases evolved and referring to tables, the temperature of the heated coil is obtained. M.1750.

Measurement of Work.

588. Watt's steam engine indicator. Lent by E. A. Cowper, Esq., 1890. Plate IX., No. 6.

This instrument was introduced by Watt, but the period of its invention is uncertain from his having kept it secret, owing to the very great assistance he found it afforded him in adjusting the valves of a steam engine. In 1796 he published a description of a pressure gauge consisting of a small spring loaded piston for connection with the steam cylinder of an engine, but in this form it was only a modification of his vacuum gauge (*see* No. 561). The important addition to the above of a pencil on the piston-rod, arranged for marking on a sheet of paper moved by the engine, is believed to be due to John Southern, one of Watt's staff. As thus improved, the instrument became a recorder of the pressure existing in the cylinder at every point of the stroke, and gave a diagram from which the work done during the stroke was easily determined. In Watt's patent of 1782 there is a diagram of the pressures throughout the stroke of an engine working expansively, but this is clearly the result of calculation, and it is not probable that the indicator had at that time been invented.

The instrument shown formerly belonged to one of Boulton, Watt & Co.'s agents in Manchester, while the diagram was taken in 1840 by Prof. E. Cowper.

The indicator has a vertical brass cylinder 1·13 in. diam. (one sq. in. area) fitted with a piston, the upper extremity of the rod of which is provided with a pencil. The piston is connected with the top of the indicator cylinder by a helical spring, so that any variation in the pressure below the piston will lengthen or shorten this spring, and thus cause the height of the piston to be a measure of the pressure below it. The lower end of the indicator cylinder is placed in communication with one end of the engine cylinder, so as to measure the varying pressure during the stroke. The motion of the paper was usually obtained from a point in the bridle rod of the parallel motion, the return movement being given either by string connected with a helical spring or by hand.

Owing to the low steam pressure employed by Watt, the connection between the indicator and the cylinder was made throughout by taper sockets and plugs, several of which are shown. On the older Watt engines the cylinder lubricators are also fitted in this way, screwing being adopted later when higher pressures were used. M.2299.

589. McNaught indicator. Lent by Messrs. Bryan Donkin & Co., 1888. Plate IX., No. 7.

This is a small example of the improved form of Watt's indicator, believed to have been introduced by Mr. John McNaught about 1825–30, in which, by the substitution of a drum for carrying the paper in place of the flat board, several serious practical difficulties were avoided.

The specimen, which, on account of its compactness, is probably not one of the earliest shown, has a drum 1·5 in. diam., and would give a diagram about 4 in. long by 3 in. high. The drum is removable, but is without clips, the paper having to be secured in position by cement. The piston is 0·25 sq. in. area, and is directly connected with the pencil, the scale of pressure being 10 lb. to 1 in. M.1967.

590. McNaught indicators. Received 1897.

These three examples of early indicators were made by Messrs. Chadburn Bros., and differ somewhat from No. 589.

The largest one has a cylinder 0·5 sq. in. area with a travel of 4 in., while the drum is 2·2 in. diam., so that a diagram about 4 in. by 6 in. could be obtained. It has a combined pin and clip attachment for the metallic paper, and the marking point is connected with the piston by an arm having an adjustable spring hinge, to give uniform pressure. The scale of the spring is 10 lb. to 1 in., but the piston rod is extended upward, so that additional pressure can be applied by means of another spring contained in a removable cap when higher pressures are being used, the scale of the combined resistance being 30 lb. to 1 in. There is in the box an independent bracket with a guide pulley, in addition to the pulley on the instrument; the weight complete with case is 12·5 lb.

The smallest specimen has a cylinder of 0·25 sq. in. area with a stroke of 2·5 in., while its drum, which is 1·5 in. diam., is fitted with the now usual spring clip for securing the paper. A diagram about 2·5 in. by 6 in. could be obtained, and the spring has a scale of 10 lb. to 1 in., but there is an additional spring in a cap for use on high pressure engines.

The other example has a drum 1·9 in. diam. for the paper, arranged outside and concentric with the cylinder. The piston has a travel of 3 in., and the diagram would be about 3 in. by 5 in. The piston-rod has a crosshead passing through a guide slot and provided with a spring-hinged arm carrying the marking point and reaching downwards to the drum. M.2976.

591. Locomotive indicator. Lent by the Great Western Railway Co., 1889.

This is a steam engine indicator, designed by Sir Daniel Gooch, for taking diagrams from locomotives running at high speeds. The diagrams are drawn on a continuous roll of paper, instead of on detached sheets as in the ordinary forms of indicator. The paper is pulled through by a pair of rollers driven by a belt from an axle of a locomotive or from the crank-shaft of an engine. The paper is kept back by a weight and cord, which tends to resist the unwinding of the paper from the reel; a similar arrangement of weight and cord causes the winding up, upon another reel, of the used paper. The cylinder is horizontal, and the piston-rod is attached to the short end of a lever which on its long end carries the pencil. A pair of bowed steel springs press on the end of the piston rod. An example of the diagram obtained is shown. M.2269.

592. Richards steam engine indicator. Lent by Messrs. Elliott Bros., 1888. Plate X., No. 1.

This well-known form of indicator was introduced by Prof. C. B. Richards in 1862, and, and, except for high-speed engines, is still in use. The great

improvement it contained was the employment of a multiplying arrangement by which the stroke of the indicator piston is reduced, and the great distortion of the diagram, through the inertia of the moving parts of the instrument, is generally avoided. The capacity and convenience of the apparatus was also improved in other respects, and most of the instruments since introduced have followed the methods that Richards invented.

The instrument consists of a small cylinder containing a piston held by a spiral spring. A drum is also provided to carry the paper on which the diagram is to be drawn, as in McNaught's instrument, but the paper arm is some little distance from the cylinder. Round the cylinder is fitted a collar with two projecting arms which support the two fixed points of a Watt parallel motion. The parallel point of this motion carries the pencil, and the piston is connected with one of the bridle rods at the point that has only one-fourth of the motion of the pencil. Owing to this arrangement, the pencil can be swung round to be in contact with the paper just when desired while the instrument is in action, a feature also of the greatest practical importance.

The example is fitted with the detent of Mr. Darke, which is simply a pawl which can at will be allowed to engage in the teeth of a ratchet wheel formed on the drum, and so stop its rotation by preventing its return under the action of the drum spring as the cord slackens. M.1887.

593. Kenyon's pistonless indicator. Lent by Messrs. Isaac Storey & Sons, 1890.

In this steam engine indicator, patented in 1878 by Mr. J. W. Kenyon, a Bourdon tube takes the place of piston and spring. The motion, under varying pressure, of the free end of the tube is multiplied by a lever in the ratio of about 5 : 1, and the pencil is constrained to move in a straight line by Watt's parallel motion applied as in Richards's indicator. The connection between the tube and the parallel motion is by a rod with ball joints which enables the pencil to be drawn back from the paper on the drum when required. The drum is fitted with a stop motion, consisting of a small lever by which it can be raised sufficiently to disengage a short driving peg attached to the cord pulley. M.2292.

594. Darke's indicator. Lent by Messrs. Elliott Bros., 1888.

This arrangement of high-speed indicator was patented by Mr. E. T. Darke in 1879. To minimise the inertia of the indicator piston, its rod is made hollow, while its motion is multiplied four times by a simple lever; the piston rod carries a sleeve, which slides on this lever, and the pencil-holder slides similarly, but is guided in a vertical slot instead of by linkwork.

The paper drum has an external clamping bar by which the paper is held; the paper is in a continuous roll within the drum, and enough for a single card is exposed externally and secured. The instrument is also fitted with Darke's detent (*see* No. 592). M.1887.

595. Crosby's indicator. Lent by the Crosby Steam Gage and Valve Co., 1896.

This indicator, patented by Mr. G. H. Crosby, of Massachusetts, U.S.A., in 1879–82, is specially designed for taking diagrams from quick revolution engines. For this reason the size and weight of the moving parts have been reduced and their travels shortened, so as to minimise the disturbances due to momentum.

The piston is 0·5 sq. in. area, and its travel is multiplied six times by the levers connecting it with the pencil, but the linkage possesses only slight inertia. To reduce the piston friction the loading springs are double with a ball connection to the piston to ensure central pressure. Round the cylinder

is an annular chamber open to steam, and serving as a steam jacket. The return movement of the drum is performed by a strong spiral spring of limited range, the intention being to moderate the fluctuation in the string tension due to the inertia of the drum. M.1943.

596. McInnes-Dobbie indicator. Lent by Messrs. Dobbie, McInnes, Ltd., 1905.

In this steam-engine indicator, which is an improved form of one patented by Mr. T. S. McInnes in 1887–8, a non-conducting vulcanite sheathing on the cylinder and other parts allows the operator to manipulate the instrument when hot and to change the spring without discomfort. The helical pressure spring is placed outside the cylinder which is open at the bottom to facilitate cleaning. The piston is of case-hardened steel, recessed; it is 0·5 sq. in. area and its motion is magnified six times by the pencil mechanism. The cord pulley frame can be set to give the cord a lead in any direction, and the length of the drum cord can be adjusted by means of a spring clip.

The example shown is a large size instrument for speeds up to 250 rev. per min.; smaller indicators of the same type are made for speeds up to 800 rev. per min. M.3396.

597. Tabor indicator. Lent by Messrs. John Musgrave & Sons, 1890.

In this instrument the parallel motion is obtained by causing a small roller attached to the pencil arm to travel in a suitably curved guide fixed on the indicator cylinder cover. The piston rod is attached to the piston by a ball-and-socket device, to prevent any tendency to bind, and with the same object the springs are double threaded. The paper drum is fitted with a detent stop motion, and a neat universal guide pulley gives a true lead to the cord from any direction. M.2307.

598. Wayne's indicator. Made by Messrs. Elliott Bros. Received 1902.

In this modification of the steam-engine indicator, patented by Mr. M. J. Wayne in 1893, a semi-rotary piston is employed to actuate the pencil arm without the intervention of any linkwork.

The piston consists of a diametral plate, capable of working steam-tight within a cylindrical chamber having two fixed abutments, on opposite sides of which are inlet and outlet ports, as shown in the attached diagram. The indicator spring is of the double helical type, but works in torsion, and resists or measures the action of the steam by checking the rotation of the piston. The outer end of this spring is secured in a groove on the axle of the piston, while the inner end terminates in a brass plate having two holes fitting upon steel pins which project from the cylinder cover and allow the spring to shorten as the torsion is increased. To the opposite end of the piston axle the arm carrying the pencil is secured, and to allow for the circular path it describes, the diagram paper is held as a cylindrical surface by circular clips concentric with the piston axis and attached to an aluminium sliding frame. A string secured to one end of this frame imparts the reduced motion from the engine piston, and the return motion is obtained by a spring barrel. In the example shown, instead of the usual pencil, a hard steel tracing point is employed marking on black-faced paper.

To enable this instrument to obtain a diagram from an engine of exceptionally high speed, without the usual distortion due to the inertia of the moving parts, it is provided with an apparatus (shown detached) for taking the diagram in such cases in layers or "lines." This attachment, which can be secured to a horn projecting from the cylinder,

consists of a segment of a worm wheel with a screw operated by a winch handle, and a steel tongue passing through a slightly elongated hole in the piston axle. By these means the rotation of the piston is limited to the amount resulting from the backlash in this hole, so that the pencil moves only through a small portion of this ordinary angular travel ; but, by turning the worm wheel slowly throughout its range, the series of layers are placed together in a way that gives a complete average diagram free from vibration disturbances, as shown in an attached print. M.3258.

599. "Simplex" indicator. Lent by Messrs. Elliott Bros., 1905.

In this steam-engine indicator, which is a modified form of one patented by Mr. M. J. Wayne in 1894, the ordinary helical spring is replaced by a bow spring situated outside the cylinder away from the action of the steam. This can be easily removed and replaced, as its ends simply fit into grooves provided in the top of the extended piston rod and a fixed piece above it, and are retained in position by a small spring pin in one of the grooves engaging with a notch. The piston is 0·5 sq. in. area, and its travel is magnified four times by the pencil mechanism which consists of a pantograph combination of levers.

A detent stop motion is fitted to the paper drum, and the tension of the drum spring can be adjusted by means of a milled head attached to its lower end. M.3383.

600. Crosby "New" indicator, with continuous drum. Presented by the Crosby Steam Gage and Valve Co., 1913. Plate X., No. 2.

This indicator, patented by the makers between 1879 and 1907, is generally similar to No. 595, but it has an external spring and is fitted with a special drum for automatically taking a series of diagrams on a continuous strip of paper. This type of drum is very useful where the load varies constantly, as in winding or rolling mill engines, and also when it is desired to take separate diagrams at intervals too short to allow of the card being changed in the ordinary way.

The indicator piston has a spherical edge and an area of 1 sq. in.; the pencil connection is made by a small rod fitted inside the hollow piston rod and terminating at its lower end in a ball joint. The piston rod is extended upwards and one end of the spring is clamped to the end of it; the lower end of the spring is fitted to a screwed nose fixed to a bridge piece mounted above the cylinder, and it may be screwed up or down to adjust the position of the pencil. This arrangement removes the springs from the effects of the high temperature and facilitates changing them.

The continuous drum is mounted on the indicator arm in place of the ordinary one, and has an external drum 2 in. diam. rotated by a cord and returned by a central helical spring. This drum has a vertical slot in it, within which the roll of paper is mounted on a removable spindle. The paper passes from this roll round outside the drum, and through the slot on to a smaller internal drum, to which its end is clipped ; the edges of the slot are provided with anti-friction rollers. The paper is wound on to the central drum by means of two ratchet clutches, one connecting the outer drum with the inner drum and the other connecting the inner drum with the fixed central spindle. The inner clutch holds the central drum stationary for a certain space at the end of each outstroke of the main drum, so that the latter overruns the inner drum, and so winds the paper on to it ; this clutch can be so adjusted that the advance of the paper at each revolution of the main drum can be regulated to give the desired number of diagrams per foot of paper. The motion of the paper is stopped by throwing out of gear the pawl of the outer ratchet clutch. A fixed pencil is mounted on the drum to continue the atmospheric line on the moving paper. The cord guide of the drum can be set in any position to suit the lead from the engine.

The drum takes a roll of paper 2 in. wide and 12 ft. long, and gives a diagram 4 in. long. M.4112.

601. Indicator reducing wheel. Presented by the Crosby Steam Gage and Valve Co., 1913. Plate X., No. 2.

This appliance, patented by the makers between 1901–7, is a compact arrangement for reducing the stroke of the engine to the stroke of the indicator; it is attached directly to the indicator cock, and carries the indicator above it.

An arm extending from the indicator connection supports a horizontal spindle running in ball-bearings and carrying a pulley, round which the indicator cord is wrapped and secured. A vertical spindle is fixed below the arm and carries a light pulley, round which is wrapped another cord the end of which is connected with the engine crosshead. The two pulleys are connected by bevel gearing with a ratio of 3 : 1, and the horizontal spindle is rotated against the action of an adjustable helical spring contained in a projecting casing. The upper or stroke pulley consists of a number of movable concentric rings by means of which its diameter may be varied to suit different engine strokes from 14 in. to 72 in.; this pulley is connected with the spindle through a clutch which allows the pulley to be held stationary by means of a spring detent, so that the motion of the indicator may be stopped when desired. The lower drum is fitted with a moving guide for properly coiling the cord. M.4112.

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602. Coffin's averaging instrument. Lent by Messrs. John Musgrave & Sons, Ltd., 1890.

This is a special form of planimeter arranged for measuring indicator diagrams. Starting from a point in the toe of the diagram, and with the measuring wheel at zero, the tracing point is led round the diagram when, on completing the circuit, the fresh reading on the wheel is the area of the diagram in square inches. By now sliding the tracing point vertically up the diagram, until the measuring wheel again reads zero, a height is obtained equivalent to the mean ordinate, and when measured with the indicator scale gives the average mean pressure throughout the stroke. M.2308.

603. Amsler planimeter. Made by Messrs. Elliott Bros Received 1909.

This is an ordinary planimeter of the proportional type, arranged so that the mean heights of indicator diagrams can be directly read. Two steel points are fitted to the instrument, one fixed at the back of the main bar, near the tracing point, and the other to the sliding piece that carries the hinge and the recording mechanism. The distance between the points is equal to the length of the tracing arm. The points are set so that the distance between them is equal to the length of the diagram to be measured, and the tracing point is carried round the area in the usual manner. The difference in the readings of the recording mechanism, the small divisions on the roller being units, will give the average height of the diagram in fortieths of an inch. A brake is fitted to the roller to prevent it from moving when measuring, for averaging, the sum of a number of similar diagrams—an addition due to Mr. Druitt Halpin in 1884. M.3635.

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604. Transmission dynamometer. Made by Messrs. Siemens Bros. & Co. Received 1887.

This apparatus for measuring the power transmitted by a belt connecting one pulley with another, is an improved form of the dynamometer brought

out by von Hefner Alteneck in 1872. A somewhat similar arrangement had been proposed by George Davis as early as 1843.

The amount of power that is being conveyed at any instant is determined from the difference in the tension of the tight and slack sides of the belt, and this is measured by an adjustable spring balance, which brings a swinging pulley back into its normal position while it is being oppositely acted upon by the two sides of the belt. The apparatus is arranged in a rectangular frame, which is supported at a suitable height by a rigid column; at the corners of the frame are guide pulleys, by which the two sides of the driving belt are brought near together and parallel, but these parallel portions are forced apart again, in the middle, by a single pulley carried on a swinging lever provided with a counterbalance weight and a spring balance. When in use, the spring balance is adjusted by hand till the swinging lever is brought to the normal position; an oil "dash-pot" is added to damp out vibrations, and two intermediate guide pulleys keep the two angles of the belt equal.

M.1877.

605. Transmission dynamometer. Made by R. Shepherd, Esq., 1892.

This form of dynamometer coupling was introduced about 1882 by Profs. W. E. Ayrton and J. Perry. The adjacent ends of the transmitting and receiving shafts are coupled by tangential helical springs, the extension of which indicates the torque transmitted. The reading is obtained upon a fixed scale, by means of a bright bead revolving with the coupling and moved radially by the extension of the springs, so that the diameter of the circle it describes varies with the torque. M.2660.

606. Spring dynamometer. Received 1914.

This form of dynamometer, or force measuring instrument, was patented by Mr. T. H. Ward in 1883.

It consists of a spring of oval form, the long axis of which is extended by the force to be measured; this results in the contraction of the short axis, and this motion is transmitted, by a rack attached to one side of the spring, to a pinion attached to a rotating pointer mounted, with a dial, on the other side of the spring. A second pointer, moved by a pin on the first one and held by friction, registers the maximum force. The dial is graduated from 0 to 400 lb. in 5 lb. intervals Inv.1914—402

PUMPS.

In this section are included appliances for lifting and forcing liquids and gases against a head; nearly all are motors reversed.

Bailing Appliances.—This class includes nearly all the apparatus known to the ancient world; they were originated in the remote past, and the greatest advance is traceable to the East, where, owing to the exigencies of the climate, the practice of irrigation was developed.

The simplest appliance is a gourd or other vessel lifted by hand; an obvious addition to the vessel is a rope whereby water could be drawn from a greater depth. The pulley, windlass, capstan and tread-wheel were used as aids in winding the rope; indeed, these mechanical powers may have been originated for performing this service. The work of lifting the vessel is saved by suspending it, either from a fixed point, as in the Dutch scoop and in the somewhat similar bail scoop, or from the longer arm of a counterbalanced lever, as in the "swoop" or "swape," which under different names has been most extensively used by all races in the past and continues in use, *e.g.*, the Egyptian shaduf, at the present day. To save human labour, the power of draught animals, flowing streams, or the wind is utilised in extensions of these ideas, arranged to repeat the operation automatically, such as the wheel with buckets on the rim, variously known as the "noria" (*see* No. 607), the Persian and the Chinese wheel; the endless chain of pots or "sakieh"; the Chinese pump (*see* No. 610) and its derivative the chain pump; rising and falling buckets; the tympanum (*see* No. 608), and the reversed water-wheel or scoop-wheel (*see* No. 609). Another appliance dating from the historical period is the water snail or Egyptian screw attributed to Archimedes, 240 B.C.

Pumps of this class are simple in construction, but their efficiency is low, their height of lift, with the exception of the windlass and bucket and of the chain pump type, is limited, and they can only deal with small quantities; they are consequently little used by Western nations.

Reciprocating Pumps.—The idea of a diaphragm or piston reciprocated within a closed box to exert pressure on a liquid would appear to have been first exemplified in the syringe. The provision of suitable valves to direct the streams resulted in the force pump, which appears to have been known more than 200 years B.C., as it is attributed to Ctesibius. Hero of Alexandria, about 50 A.D., describes the manual fire-engine with two single-acting cylinders immersed in the water to be raised and provided with clack or poppet valves. The suction pump was in use about the same time, although the reason why water would not follow the piston to a greater height than about 25 ft. was not understood till the existence of atmospheric pressure was demonstrated in the 17th century. The height in

excess of 25 ft. may be overcome either by having a solid piston when the pump is of the suction and force type, or by having a valve in the piston when direct lift is resorted to. The plunger or ram force pump in which the packing is transferred from the piston to the cylinders was known to the Romans; since reintroduced by Trevithick in 1797 for mine drainage, it has been the form used for the highest pressures, *e.g.*, hydraulic work. A closed collapsible connection between the piston and its fixed abutment gives the diaphragm pump (*see* No. 634) or bellows. As indicating the extensive nature of pumping operations undertaken with simple means, the water supply of the cities of Augsburg and Bremen, as well as the costly waterworks for supplying the needs of the palace of Versailles, completed in 1682 by Swalm Renkin or Rannequin, may be cited. Another important waterworks was that established at London Bridge in 1582 by Peter Morice and subsequently extended (*see* No. 612).

The great need that existed for elevating large quantities of water for waterworks or mine drainage directed attention to new sources of power. Savery's engine for raising water by the direct pressure of steam (*see* No. 37) was applied in 1699 at York Buildings, in the Strand, but it was not till after Newcomen's atmospheric engine was brought out in 1712 (*see* No. 41) that any large development took place; for three-quarters of a century the steam engine was confined solely to the duty of working large pumps. In the hands of James Watt and his successors this led to high efficiency in the well-known Cornish engine (*see* No. 615).

The suction and force pump had been made double-acting at an early period by closing both ends of the barrel and duplicating the valves, so that by placing the barrel in line with a steam cylinder a simpler type than the beam engine is arrived at. If rotative parts are omitted the piston is free and can act on the water without shock. The difficulty of making the piston-rod control the movement of the valve was overcome in 1844 by Henry R. Worthington, and the direct-acting type was introduced. The special case where the valve of one cylinder is controlled by the piston-rod of another placed by its side gives us the duplex type (*see* No. 623). In neither type can the steam be used expansively, but the difficulty has been overcome by compounding or by "compensators" so that this type can compete in economy with any other.

If water under a high head is available, its energy may be utilised so as to raise a smaller quantity to a higher head or *vice versâ*. Such water-pressure engines appear to have had their origin in Germany in 1748, and to have been introduced into this country in 1765; Trevithick adopted the construction in Cornwall in 1798 and other engines have since been built (*see* Nos. 635 & 636), but the type is more common on the Continent.

Owing to the elasticity of gases, changes in volume and temperature take place in compressing them. At the low pressures used for supplying air to furnaces (*see* Nos. 650 & 651) the rise in temperature is negligible, but at high pressures it becomes

serious; in the compressors of Dubois and François, used for supplying the rock-excavating machines at the St. Gothard Tunnel in 1873, it was obviated by injecting cold water into the cylinder, hence known as a "wet" compressor. This had the advantage of filling the clearance space and ensuring complete discharge of the air, but it limited the speed of working to about 100 ft. per min. and made the air unnecessarily moist. In the "dry" compressor the cylinder is jacketed and cold water is circulated through it, about half the loss of work through heating being thereby avoided; clearance spaces must be reduced to a minimum and the only limit of speed is that at which the valves will operate satisfactorily. For compressing air to very high pressures it is now usual to work in stages, the pumps, of diminishing diameters, being usually on one long piston-rod, the air compressed in the first pump passing through external cooling pipes or "intercoolers" before being further compressed in the second pump, and so on; in this way the loss of power through the thermal changes during compression can be greatly reduced, and several mechanical difficulties are avoided.

Rotary Pumps.—These, although acting by force and suction, differ from the preceding class in the use of a rotating or oscillating "piston" to effect the enlarging and contracting of the pump chamber. Ramelli in 1588 describes one with an eccentric chamber and rotating blade (*cf.* No. 667), and also one in the form of two spur-wheels geared together in a closely-fitting casing (*cf.* No. 668). Rotary mechanism has been much more successful when applied to pumps than to motors, especially when restricted to moderate heads where the leakage due to the packing is small. The low speed of rotation that may be adopted is also an advantage.

Centrifugal Pumps.—These differ from the preceding classes in that the energy is used in giving momentum to the water instead of acting by positive pressure. In 1682 Denis Papin schemed the Hessian pump which had a wheel or impeller with four straight radial blades arranged in a circular casing. Several arrangements of Barker's mill reversed were proposed during the succeeding century, but nothing better appeared till 1818, when the Massachusetts pump was introduced; from this the rise of the present centrifugal pump may be said to date; this differed from Papin's mainly in being immersed in the water to be lifted, and in having an eccentric casing; it is thus less inefficient than the circular casing in converting the kinetic energy, that has been imparted to the water on leaving the impeller, into pressure energy. In 1839 Andrews brought out the efficient spiral or volute casing. In 1849 J. G. Appold determined by experiment the most efficient curve for the blades of the wheel (*see* No. 669). About 1850 Prof. J. Thomson first suggested the whirlpool chamber—a space surrounding the wheel in which a free vortex could be formed.

For high lifts the peripheral speed of the wheel must be high and the skin friction becomes serious. Gwynne and others early tried to obviate this by employing two or more pumps in series, the several wheels being on the same shaft, but the

efficiency proved low. Recently Sulzer and others have succeeded in obtaining efficiently any desired lift. A further advance in efficiency has been obtained by centrifugal pumps in which the passages are formed like those of an outward flow turbine reversed; these have also been arranged similarly in series for high lifts. Low first cost and upkeep and their capability of dealing with very large quantities of water in which solid matter may be in suspension, are the chief advantages of centrifugal pumps.

Where large volumes of air at a slight pressure are required for ventilation of mines and buildings the form known as a fan is almost exclusively employed (*see* Nos. 677–679).

Hydraulic Rams.—In these machines the temporary rise in pressure which results when the flow of water through a long pipe is suddenly arrested is employed to raise a small quantity to a considerable height. The first to make a practical application of the principle was John Whitehurst, who in 1772 took advantage of the use that was made of a cock at the ground floor of the house, in order to raise water to a cistern on the upper floor. In 1796 J. M. and J. E. de Montgolfier independently invented the ram and made it self-acting by using, in place of the cock, a valve loaded so as to open again after the water had come to rest (*see* No. 681). Rams are now constructed which will lift water from a different source to that whence they obtain their power so that a dirty stream may be utilised (*see* No. 682). To raise water in quantity rams have been constructed with the momentum valve operated quietly by compressed air. Rams usually have a low efficiency, but require little attention and maintenance.

Bailing Appliances.

607. Photographs of current wheels. Presented by H. W. Dickinson, Esq., 1913.

These wheels, known as *naura* of which there are four altogether, are situated in the River Orontes at the ancient city of Hama, Syria. The wheels lift water for irrigation and domestic purposes in pots attached to the rim. They are driven by float boards on the rim dipping into the stream. The wheels are wholly of wood and the largest is said to be 70 ft. diam.

M.4256.

608. Model of scoop wheel (working). (Scale 1 : 10.) Constructed by Mons. P. Regnard, 1899.

This is a modern form of the "tympanum," which was an ancient water-raising appliance when described by Vitruvius, in the first century A.D. It consisted of a horizontal drum divided into four chambers by radial partitions, and partly immersed in the water that was to be raised; when the drum was rotated, water entered each chamber by an opening at the circumference, and afterwards escaped through another opening along the main axle. De la Faye, about 1730, replaced these chambers by pipes bent to an involute curve, thus greatly increasing the efficiency by reducing the useless circumferential velocity given to the water.

About 1830, Cavé brought the machine to the present form by fitting the drum with partitions curved to an Archimedean spiral, by the use of which

the water is raised vertically through equal heights for equal angular movements of the wheel, so that the resistance is uniform. Cavé constructed several of these wheels 23 ft. diam, 3·28 ft. wide, which were immersed 4 ft. in the water to be raised. They were driven at a speed of 10 rev. per min. by spur gearing, as shown, and are stated to have raised 8,800 gal. of water per min. to a height of 3·28 ft. with an efficiency of 85 per cent.

As wheels of this kind can only raise water to the height of their axles, their use is restricted to low lifts; also, any temporary lowering of the head water in no way reduces the power required, and their effective speed is very limited. On the other hand, they have no inferior limit of speed, and can pump any kind of water without undue wear, while, under suitable conditions, their efficiency is high. M.3045.

609. Model of scoop wheel. (Scale 1 : 25.) Made from a drawing supplied by J. L. Pierson, Esq., 1913.

This scoop wheel, which resembles an undershot water wheel reversed, is used for raising water in low lifts, *e.g.*, as required in the drainage of low-lying land. It has been but little used in this country, except in the Fen districts, but has attained a high development in Holland.

The scoop wheel represented is one erected in 1896 at Keizersveer, on the southern mouth of the Maas. The maximum lift here is 1·4 m. (4·6 ft.); the wheel is so situated that 0·19 of its diameter is immersed, and the plane of the scoops makes an angle of about 13 deg. with the radius. The number of scoops is such that their distance apart at the circumference gives quiet and regular action.

The wheel is 7·5 m. (24·6 ft.) diam. by 2·5 m. (8·2 ft.) broad and has 22 scoops, which are consequently 1·07 m. (3·5 ft.) apart on the circumference. The wheel is built up on 3 cast iron spiders bolted together with distance-pieces, and keyed to the shaft. The scoops are of sheet iron supported by flat iron arms 120 mm. (4·72 in.) by 16 mm. (0·63 in.) made in the form of frames with angle-iron bearers; of these there are two in the width, bolted to the spiders and to rings of the same section situated near the circumference. The arms are stayed by bars of the same section bolted to the spiders. In order to insert the scoops between the rings, each is made in two parts, with a butt strap down the middle. The scoops stand back 5 cm. (2 in.) from the faces of the wheel pit; wooden and sheet iron extension-pieces are bolted to the edges so as to leave a clearance of 5 mm. (0·2 in.) only. The wheel is driven by an engine with a pair of horizontal cylinders working at 80 lb. pressure. The speed is reduced by mortice wheel and pinion, in the ratio of 1 : 14, to 4 rev. per min., at which speed the water raised amounts to 250 cub. m. (8,830 cub. ft.) per min. Tests in 1898–9 showed a steam consumption of 9·6 kg. per indicated h.p. per hour, and an efficiency of 58 per cent.

The delivery side of the wheel is provided with a swinging flap which serves to hold up the water in the interval between one scoop's delivery and the next. The wheel pit is provided with dock gates and sluices so that it can be emptied for repairs, etc.

The Dutch scoop wheel is wider on the face than most of those used in the Fens. The wheel at Pode Hole is 5 ft. wide and that at Southery 2 ft. 7 in., while many are only 12 in. to 15 in. wide; but they are run faster than the Dutch wheels, *e.g.*, a 40 ft. wheel runs at 4 rev. and a 24 ft. wheel at 6 to rev. per min. Inv. 1912–13.

610. Models of Chinese pumps. (Scales 1 : 12 and 1 : 24.) Received 1862 and 1895.

These illustrate a form of pump frequently used for irrigation in China. There is a long inclined trough dipping into the lower water at one end and reaching above the higher level at the other; in the trough is the lower half

of an endless chain provided with float boards just fitting it and returning over a spoked axle at each end. The upper axle in one model is provided with cranks driven by men working connecting rods, and in the other by an ox turning a gin with wooden crown gearing. M.1670 and M.2190.

Reciprocating Pumps.

611. Reproductions of Roman pumps. Received 1914.

These are reproductions of two plunger pumps discovered on the site of a foundry at Bolsena, Etruria and now in the British Museum. In some respects the originals have not been followed, *e.g.*, the reproductions have been made in section, the better to show constructional details. The wooden supports are conjectural. No date can be assigned confidently to the originals; possibly they are as early as the 1st century A.D.

The pump barrels, plungers, rising main, &c., are separate bronze castings, probably made by the *cire perdue* method. The connections are made by socket joints apparently soldered. There is good evidence of parts having been turned on the outside but nothing can now be gathered as to whether the barrels, &c., were bored. Each plunger has a knuckle joint with socket for the rod which must have been actuated from a rocking beam above; what appear to be the journal and socket for this beam are shown in one instance. The plungers are exceptionally short and there is no evidence of any packing so that leakage must have been excessive, but the design is good in that it gave a continuous discharge.

In the larger pump the valve seating is a disc with an eccentric hole covered by a clack valve which, from its likeness to a coin, was known by the Greeks as *'ασσαριον*. This clack hangs loosely on a stud riveted in the seating and burred over slightly to prevent the clack coming off. The plungers are 1·35 in. diam. and the stroke was 5·1 in.

In the smaller pump all the valves are of the drop type; a pin through the stem prevents the valve rising too far. In the case of the foot-valve, its seating with the guiding ribs is soldered in; in the case of the delivery valve, ribs are cast on the interior of the pipe and a guide for the valve spindle soldered to them. The plungers are 1 in. diam. and the stroke was 3·25 in.

(*See* British Museum Handbook to Greek and Roman Life, p. 110.)

Inv. 1914—702 & 703.

612. Engraving of London Bridge waterworks. Presented by C. K. Eley, Esq., 1910.

This print shows, generally, the arrangements employed for 240 years at Old London Bridge for supplying the City with water from the Thames.

The original scheme was due to a Dutchman named Peter Morice, who in 1582 obtained from the City a lease for 500 years at the rent of 10*s.* per annum of the arch nearest the City end of the bridge. Two years later the second arch was similarly leased, and in 1701 the third also, when the undertaking was converted into a company.

The print shows one unit of the plant installed by George Sorocold at the latter date. A tide-wheel, 20 ft. diam. with 26 floats 14 ft. long by 1·5 ft. deep, was raised and lowered to suit the state of the tide by mechanism patented in 1693 by John Hadley. The wheel was supported on bearings near the fulcra of two levers 16 ft. long, which were operated by pitch chains and gearing in the ratio 1 : 68, so arranged that one man could work both. In practice, however, it was found to be superfluous, and was not used. On the axis of the tide-wheel were two cog-wheels, each gearing in the ratio 1 : 2·2 into a lantern wheel on the fulcrum axis. This was coupled to a four-throw crankshaft driving, by connecting rods and beams, 8 pumps 7 in. diam. by 2·5 ft. stroke drawing water from the river and forcing it to a height of 120 ft. The maximum speed of the tide-wheel was 6 rev. per min. The efficiency of the pumps was about 60 per cent.

The plant remained in operation till 1822 when the bridge was removed to give place to the present one. M.3753.

613. Model of Cornish mine pumps. (Scale 1 : 12.) Made by J. Arthur, Esq., 1843.

This is a general representation of the complete arrangement of pumps employed in a deep mine and is consequently not accurately to scale.

The work is performed by a single-acting condensing steam engine, the beam of which projects through the end wall of the engine-house, so that the outer extremity is over the mine shaft; here also are the timber sheers, for use in lowering the pumps and during repairs, while they also carry the stationary ends of the radius links of the parallel motion guiding the main pump-rod. This rod is built up of heavy square timbers, and extends nearly to the bottom of the shaft; its weight is largely counterbalanced by a loaded rocking beam, or balance-bob, usually arranged at the surface and not as shown in the model.

The lowest pump is of the bucket type at the bottom of which is a strainer, and some little distance above it a box containing one or more non-return or suction valves; above them is the bucket, which also contains valves and is worked by a rod passing up to its rising main and connected by bracket pieces to the sides of the main pump-rod or spear, and at the top of its rising main delivers into a cistern in the shaft. From this cistern rises a vertical pipe, to the side of which is connected the barrel of a plunger pump; the plunger is bolted to the side of the main pump-rod, while the valve boxes are arranged in the rising main, access being given by side doors. This rising main may extend right to the surface, or to an adit; but, if the lift is excessive, a similar pump takes it to the next stage and so on, thus avoiding excessive pressure or concussion on the valves and pipes. M.2652.

614. Models of mining pumps. (Scale 1 : 8.) Made by Carl Schumann, 1851.

In each case the pump is of the bucket type, and has a single foot valve at the bottom of the working barrel, while the pump-rod passes up through the delivery pipe. In one of the examples the pump and its pipes are made in cast iron; the latter have socket joints rendered tight by the use of hemp and metallic lead; in the other two examples the pipes are of timber hooped with iron, and are usually made from tree trunks bored out. The various lengths are socketed together and retained by three timber dogs at each joint; the working barrel is in iron, but the valve boxes are in wood and have side doors; in all cases the pumps and pipes are shown supported by timber beams. M.1405.

615. Cornish pumping engine (working). Lent by Messrs. Harvey & Co., 1862. Plate X., No. 3.

This is a small example of a type largely employed in waterworks, and also, with a slight variation in arrangement, for mine drainage; it is an improved form of Watt's single-acting beam pumping engine (*see* No. 57). A cylinder is situated under one extremity of the beam and a plunger pump under the other; the air pump, condenser, and feed pump are arranged between the main pump and the beam centre, while on the other side is the plug rod for actuating the valve gear.

Watt's parallel mation is employed at both ends of the beam, but for mine pumping engines the motion is required for the cylinder end only, the pit rods being connected directly to the beam. The automatic valves of the steam cylinder are three in number: the steam valve, the equilibrium valve, and the eduction valve, while a fourth valve—the main steam valve—is provided for cutting off the supply of steam from the boiler when stopping the engine, etc. The closing of the steam valve, of the equilibrium valve,

and of the eduction valve is effected by tappets on the plug rod; but the equilibrium and eduction valves are interlocked by an ingenious arrangement of two intersecting quadrants, set to prevent the possibility of both valves being opened together. The opening of the steam and eduction valves is controlled by a cataract gear, placed below the engine platform and actuated by the plug rod. It consists of a plunger, working in a fluid, *e.g.*, oil or water, and connected to the valve catches and so lifted by the descending plug rod. It is afterwards free to sink, the water or oil escaping through an orifice that is adjustable for varying the time interval.

The engine is single-acting, the steam driving the piston down while the lower end of the cylinder is in communication with the condenser. During this stroke work is done in lifting the heavy plunger, and drawing into the pump a volume of water from the suction main. At its termination the steam and exhaust valves are closed by the tappets, and the equilibrium valve opened, the latter putting the two ends of the cylinder in communication, so that the piston is drawn upwards by the weight of the pump plunger, which in its descent also forces the water in the pump through the delivery valves into the rising main. At the completion of the up-stroke of the piston a tappet closes the equilibrium valve, and so by cushioning quietly stops the downward motion of the plunger, when there is an interval of rest until the cataract plunger has descended far enough for it to lift the catches that retain the steam and eduction valves closed, and on these being released the down-stroke at once recommences. The cataract secures that a definite interval shall elapse at the end of the stroke, and so gives a ready and exact means of regulating the number of strokes made by the engine per minute.

The example shows a cataract for the steam and the eduction valves only, the equilibrium valve opening when the intersecting quadrants clear one another. It is usual in engines of any size to apply also a separate cataract to the equilibrium valve. This enables the engine to make a pause at the end of the up-stroke as well as that of the down-stroke of the piston, to give time for the main pump valves to close quietly and for the pump rods to stop quivering.

Some very large engines of this type have been constructed, *e.g.*, one built in 1858 had a steam cylinder 112 in. diam. This example has a steam cylinder 5 in. diam. and a plunger 4 in. diam., both with a stroke of 15 in.

Inv. 1862—26.

616. Models of Rittinger pumps (working). (Scale 1 : 5.) Made by J. Schröder, 1892 and 1901.

This class of pump, in which the plunger is stationary and forms a continuation of the rising main while the pump barrel is moved up and down by the spear rods, was introduced in 1849 by Herr P. von Rittinger at some mines near Chemnitz, but the idea had to some extent been anticipated in the "telescope" pump designed by Herr Althans in 1846.

One of the models represents a single-acting pump, and has only two valves, while the other is double acting and requires three valves. In both cases the rising main is provided with an air vessel and a retaining valve, and terminates in a fixed hollow plunger upon which the pump barrel slides. The lower end of the barrel is formed into a hollow plunger, which works through a gland in the suction pipe, which, in the case of the double-acting pump, is fitted with a suction valve.

In the single-acting example, during the up-stroke of the barrel, the water displaced by the stationary plunger at the end of the rising main is delivered through it, and prevented from return during the downward stroke of the barrel by the retaining valve, the spear rods, consequently, always working in tension.

In the double-acting pump, during the upward stroke of the barrel, delivery takes place as above, but in the downward stroke the lower plunger, which is of larger area than the upper one, displaces more water from the

suction pipe than will fill the space left in the barrel by the withdrawal of the upper plunger, the excess, therefore, passing into the rising main, so that in this pump water is being discharged during both strokes, while, by suitably proportioning the areas of the two plungers, the weight of the spear rods can be employed as in the ordinary plunger pump. External gland packings are used for both plungers, and the valves in the barrels are rendered accessible by side doors. M.3172.

617. Suction and lift pump (working). Lent by Messrs. Perreaux & Co., 1903.

This is a single-acting pump for working by hand power; being provided with a glass barrel, as is sometimes necessary when pumping chemicals, the course of the fluid and the action of the valves can be seen.

During the up-stroke of the piston or "bucket," the water above it is carried upward, while beneath the bucket an empty space would be left, but for the atmospheric pressure which forces the water up the suction pipe and causes it to follow the bucket. Upon the commencement of the down-stroke the water in the barrel is prevented from returning, by a valve at the bottom of the barrel, but is allowed to pass through the bucket to its upper side, by a valve within it from whence it is delivered at the next up-stroke.

The valves employed in this example are of the construction patented in 1856 by Mr. L. G. Perreaux, and are made entirely of vulcanised india-rubber. The base of the valve is a stout annular flange, by which it is held, and the passage is closed by two lips with thin edges which are forced together if the pressure above them is greater than that below.

The pump shown is 2·5 in. diam. by 6·5 in. stroke; for larger pumps the Perreaux valve is formed with 3 pairs of lips meeting at a common centre. M.3294.

618. Downton pump. Made by Messrs. J. Downton & Co. Received 1911.

This type of suction pump was patented in 1825 by Jonathan Downton and has been used largely on board ship. Its advantages are that with only one pump barrel a number of superposed buckets, of length of stroke diminished in proportion to the number, are employed, so obtaining practically a uniform delivery.

Three is the number of buckets used, and in the original design their rods were telescoped one within the other, with offsets on two of them to operate them by. In this example the rods are side by side, that of the lowest bucket being in the centre; this necessitates the upper two buckets having holes through them, but no packing is needed. The upper ends of the rods terminate in loops which slide in grooves in the top casing. The loops embrace cranks at 120 deg. on a three-throw shaft, actuated by a flywheel and handle. The suction valve is a simple clack hinged for convenience to the cover of the valve box. The pump stands on a casting for conveniently bolting it to the deck, etc. M.3939.

619. Model of a reciprocating pump. (Scale 1 : 4.) Lent by Messrs. Pontifex and Wood, 1890.

Two suction and lift pumps delivering alternately are here arranged in a cylindrical casing in a similar way to that patented in 1793 by Joseph Bramah for a fire engine. The two buckets form a diametral plate and are capable of being oscillated on the axis through 80 deg. by an external hand-lever. Beneath the buckets, a sector of the cylinder forms a suction box provided with a suction valve to each bucket. M.2296.

620. Motion diagram of a compound beam engine. (Scale 1 : 12.) Lent by Messrs. James Simpson & Co., 1893.

This is a motion diagram showing in section a Woolf compound rotative beam pumping engine. This type is largely adopted for waterworks and the one shown was constructed in 1882 for the Hammersmith pumping station of the West Middlesex Waterworks. Both cylinders are steam jacketed, and have slide valves with back cut-off plates, but the exhaust from the low-pressure cylinder is controlled by separate double-beat valves. A crank and flywheel are introduced to give a uniform stroke and to permit of high expansive working. The pump-rod descends from the extremity of the beam some distance beyond the point of attachment of the connecting rod. Both cylinders are double-acting, and the valve motion is driven from eccentrics on the crank shaft. With such an engine a duty of over 120 million ft. lb. has been obtained. The low-pressure cylinder is 47·5 in. diam. with a stroke of 96 in., the high-pressure cylinder 29 in. diam. by 65 in. stroke, and the pump, which is double-acting, is 17·93 in. diam. and 96 in. stroke. The speed is 18 rev. per min. and the indicated h.p. 206. M.2525.

621. Sectional model of Ashley pump (working). (Scale 1 : 4.) Lent by Messrs. Glenfield and Kennedy, Ltd., 1903.

This pump is constructed in the manner patented by Mr. H. Ashley in 1898, by which the whole of the valves of a deep-well pump are rendered accessible for cleaning or repairs without the pump having to be dismantled.

The pump bucket is a long tube forming two pistons connected by a hexagonal waist of smaller diameter. The bottom of the bucket is open, while the top is closed by the delivery valves, which are made as concentric rings surrounding the central attachment for the pump-rod. Each suction valve consists of a rubber disc, which opens against a spring and guard, and is mounted on a seating screwed into the flat faces of the waist; in the pump represented there are six of these valves, two on each alternate face of the waist. The pump barrel forms the bottom of the rising main, and is a casting closed at the bottom, but having inlet ports through its sides at mid-length, while the stroke of the bucket is such that these ports are always between the piston ends. During the up-stroke of the bucket, water flows through the suction valves into the space below the delivery valves, while in the down-stroke the water passes through the delivery valves into the upper part of the barrel from which it is lifted in the next up-stroke.

As the whole of the valves are brought to the surface when the bucket is withdrawn, the usual trouble involved when a suction valve becomes choked is avoided, while the absence of external valve boxes renders this arrangement of pump convenient for placing in bore-holes. The large suction valve area that can be provided permits of the pump being worked at a comparatively high speed. M.3268.

622. Model of a compound pumping engine (working). (Scale 1 : 8.) Lent by Messrs. Hathorn, Davey & Co., 1888. Plate X., No. 4.

This represents a modern horizontal compound condensing steam engine, arranged for working vertical pumps situated below the surface in a shaft or well. The weight of the pump-rods is neutralised by suspending them from what is equivalent to an equal-armed lever, so that the rods counterbalance and always move in opposite directions. Such a lever, when provided with an arm for driving from a horizontal rod, was largely used and is known as a T-bob; but it is objectionable owing to the large diameter of shaft necessary through the pump-rods being so far apart. In the model, two bellcranks, arranged oppositely and coupled together at the top, give the same result while bringing the pump-rods close together.

The steam cylinders are arranged horizontally and tandem fashion with the high-pressure cylinder in front, the piston-rod of which is connected with a long crosshead. From this crosshead two rods extend backwards, and through passages in the sides of this cylinder, to the piston of the low-pressure cylinder. The glands for these rods are at the front of the high-pressure cylinder, instead of in the rather inaccessible position between the two cylinders. From the centre of the low-pressure piston a rod extends backward through the cylinder cover to a double-acting horizontal air pump. This is combined with a jet condenser in which the exhaust steam from the low-pressure cylinder passes.

The valve motion is known as Davey's "differential," and is an interesting piece of mechanism. The slide valves of the two cylinders are on one rod, which is connected with a "floating" lever. One end of this lever receives a positive motion from the engine crosshead while the other end is caused to reciprocate by means of a subsidiary piston under the control of a "cataract" cylinder. If the crosshead extremity of the lever moves faster than the cataract end, the steam port opening is reduced or closed, so giving increased expansion with lighter loads. Should the load be removed owing to the failure of the pumps to obtain water or for any other cause, the cut-off and reversal of the valve is so rapid that the pistons never reach the cylinder ends, and in this way many serious accidents to the engines have been avoided.

M.1908.

623. Duplex pump (working). Lent by the Worthington Pumping Engine Co., 1892.

In this arrangement of pumping engine, which was originally introduced by Mr. H. R. Worthington about 1850, there are two complete double-acting steam cylinders, side by side, directly working similar pumps, but with the strokes so timed that a practically continuous discharge is maintained into the delivery main so that the engine will pump quietly even through long lengths of pipe. Each steam cylinder is provided with separate steam and exhaust ports and an ordinary slide-valve, but the valve of one cylinder is moved by the piston-rod of the other and no flywheel is introduced; the delivery is accordingly very uniform, since the resistance due to the head and friction in the pipes alone determines the variations in the speed of the pistons.

M.1910.

624. Steam pump. Lent by J. Cameron, Esq., 1887.

This type of direct-acting flywheel donkey pump was patented by Mr. Cameron in 1852, and has since been extensively adopted for boiler feeding and similar work.

The steam cylinder is arranged vertically over the pump barrel, and the pump rod is attached to an inverted kite-shaped casting which terminates in the pump plunger; within the loop of this casting is arranged a connecting-rod, attached to it and to the overhanging crank of a flywheel shaft, so that direct action is secured while the control of a crank and flywheel is retained. The slide valve is worked by an eccentric on the crankshaft, and the other end of this shaft is provided with another crank working a similar single-acting pump; the cranks are set opposite, so that the pumps deliver alternately. Sometimes double-acting pumps are substituted, while very frequently there are two steam cylinders in the arrangement shown. The pump valve bores are formed in the supporting columns which act as air vessels.

M.1878.

625. Steam pump. Contributed by Messrs. J. Withinshaw & Co., 1869.

This simple and early form of the self-contained double-acting steam pump was patented and constructed in 1867 by Messrs. J. Withinshaw and

J. E. Baker. The slide valve for the steam cylinder is worked by a tappet motion from the piston-rod, which is common to both steam and water cylinders; the tappet itself consists of a collar secured to the piston-rod and enclosed in a cylindrical sleeve which is loose on the rod but is provided with caps which are struck by the tappet when near the extremities of the stroke. This sleeve moves a lever connected with the slide valve, and an extension of the lever forms a handle by which the valve can be moved when starting.

The steam cylinder is 5·5 in. diam. and the pump 3·25 in. diam.; the steam chest cover has been removed to render the slide valve visible.

M.1116.

626. Steam pump. Made by Messrs. Hayward-Tyler & Co. Received 1910.

This is a direct-acting reciprocating steam pump, in which the steam distributing valve is operated entirely by the steam itself without the aid of any external mechanism. It was patented by Messrs J. R. Maxwell and E. Cope in 1868.

The piston of the steam cylinder is made very long and has packing rings at each end, the space between these rings being continuously open to the steam supply, while a long pocket at the bottom of the piston is open to the exhaust pipe. The piston is maintained upon the lower surface of the cylinder in the same way as a slide valve, but rotation is prevented by a screw engaging in a guiding groove along the piston (not shown). Centrally in the piston is a cylindrical slide valve, with its ends serving as pistons by which the valve is moved as the main piston reaches the ends of its stroke, steam flowing through passages in the walls of the main cylinder and piston, and exhausting through similar passages on the opposite side. The central portion of this valve acts as an ordinary slide, and the ports over which it moves communicate with their respective ends of the piston. The valve chamber of the pump has both the suction and delivery valves arranged above the cylinder at the same level, so that they are easily accessible by removing the top cover with its air chamber. The valves are solid rubber balls on gunmetal seats provided with cages to keep them in position. The piston is packed with cup leathers.

The pump shown has a steam cylinder 5 in. diam. and a water cylinder 4 in. diam. It makes 85 strokes per min. and delivers 3,500 gal. per hour.

M.3731.

627. Vertical steam pump. Lent by Messrs. Alexander Wilson & Co., 1871.

This is a small direct-acting plunger pump, with a flywheel for controlling the motion and working the slide valve. The steam cylinder is above, and, on its cover, carries the bearings of the flywheel shaft. The piston-rod forms the plunger and is consequently large—thus reducing the steam taken on the up-stroke when but little work is being done. From the plunger projects a form of crosshead sliding on a vertical guide, and from the crosshead extends upward a connecting rod to a crankpin on the flywheel. At the other end of the flywheel shaft is a small overhanging crank, working a block capable of sliding in a slot formed in an extension of the slide valve rod. This arrangement is equivalent to steam distribution by a simple eccentric with an eccentric rod of infinite length. The pump valves are arranged in a valve box attached to the pump barrel. M.2560.

628. Feed pump (working). Made by A. G. Mumford, Esq. Received 1907.

This is a direct-acting suction and force pump for boiler feeding, etc. The flywheel, controlling the slide valve of the steam cylinder through an

eccentric, is driven without the intervencion of a connecting rod by a block on the crankpin sliding in a slot at right angles to its length in the common piston rod which thus has a simple harmonic motion. The suction and delivery valves are of the mushroom type. The steam cylinder is 2 in. diam. and the plunger 1·2 in. diam. with a common stroke of 1·9 in. M.3498.

629. Direct-acting steam pump (working). Made by J. Stannah, Esq., 1891.

This machine, patented in 1876 by Mr. Stannah, has the steam cylinder above and a single-acting pump below, the large piston-rod being carried down to form the pump plunger. The cylinder, framing, and pump are all in one casting. Projecting from the piston-rod is a stud, on which is a fly-wheel free to revolve. At another point within the flywheel is attached the free end of a connecting rod, the other end of which is capable of swinging on a fixed centre on the cylinder front. As the flywheel is driven up and down the connecting rod compels it to rotate, and the momentum carries the engines over the dead centres. The motion of the connecting rod actuates a small cylindrical slide valve by which the distribution of steam to the cylinder is effected. By imagining the connecting rod to be fixed, and the rest of the engine to be free to swing, it will be seen that the arrangement is equivalent to an oscillating cylinder engine with the steam distributed by the motion of the trunnions.

This example has a 1·75 in. cylinder, 0·875 in. plunger, and a stroke of 2·25 in., and is intended to make 110 revs. per min. M.2423.

630. Steam pump (working). Lent by Messrs. Hayward-Tyler & Co., 1891.

This is a small example of a pump for high lifts, fitted with a self-governing gear patented in 1877 by Messrs. E. Cope and J. R. Maxwell and resembling that shown in No. 626. The steam cylinder and the pump are in line, and from the common piston-rod an arm projects which swings a double lever connected with the valve gear. The main slide valve is above the steam cylinder, and above it again is a smaller slide which is reversed by the motion of the swinging lever, so that when the engine has completed a stroke the small slide admits steam behind a piston combined with a main slide, which is thus forced into the position for the return stroke. The governing is effected by a cataract cylinder moved by the lever. In this cylinder is a small piston connected with the main slide valve, and an adjustable by-pass is provided by which the passage of the oil from one end of the cataract cylinder to the other can be regulated. When the engine moves at above its normal speed the cataract cylinder carries the steam valve with it, and the motion is such as to close the steam port. M.2374.

631. Direct-acting steam pump (working). Made by J. Bernays, Esq., 1892.

This pump, patented in 1884 by Mr. Bernays, is remarkable for the arrangement of crank and connecting rod by which the flywheel is connected with the reciprocating plunger, the result being that the stroke of the ram is twice the diameter of the crank path.

The machine is arranged with the steam cylinder at one end, the large piston-rod of which is carried through and forms the plunger of a single-acting pump at the opposite end of the machine. The flywheel and shaft with an overhanging crank are placed midway, the crankpin being connected with a pin on the pump ram by a connecting rod whose effective length is equal to the radius of the crank path. This connecting rod is produced backwards, and terminates in a circular end which engages alternately in two notches formed in a portion of the framing over the centre line of the flywheel shaft.

The outer extremity of the short connecting rod is in this way controlled, and the kinematic chain closed during the time it would otherwise be incomplete. The result is that the throw of the crank is increased by the length of the connecting rod at each end of the stroke. The adjacent diagram shows the positions of crank and connecting rod at various portions of a revolution, the connecting rod being coloured blue, the ram red, and the stationary notches grey.

The admission of steam is controlled by an ordinary eccentric and slide valve, but when required to drive by hand, a handle is inserted in the flywheel. The suction and delivery valves are contained in boxes with circular flanges, which can be bolted on to suit a horizontal or vertical arrangement of the pump. M.2433.

632. Direct-acting steam pump. Made by Messrs. Miller and Tupp. Received 1901.

This is a small boiler feed-pump constructed upon a system patented by Mr. J. J. Miller in 1884. The steam cylinder and the pump are a single casting, and the piston-rod forms the pump plunger; on one side of the cylinder is a chamber containing a crank-disc fixed to the shaft of an external flywheel, while an eccentric hole in this disc receives the spherical end of a pin projecting from the side of the elongated piston of the steam cylinder. The piston as it reciprocates therefore turns the flywheel, and itself undergoes considerable to-and-fro rotation. In the cylinder wall there are two steam ports, and an exhaust port between them, while the piston has two axial grooves leading to its top and bottom faces respectively, the arrangement being such that the piston, by its rotating motion, acts as its own slide valve and gives a steam distribution similar to that obtained by the use of an eccentric without angular advance (*see also* No. 117). The cylinder is 1·1 in. diam. by 0·68 in. stroke and the plunger is 0·56 in. diam. M.3202.

633. Feed pump. Lent by Messrs. G. and J. Weir, Ltd., 1907.

This is a single cylinder non-rotative pump embodying the special features patented by Messrs. G. J. and W. Weir between 1881 and 1905.

The pump is vertical with the water cylinder below forming a base and the steam cylinder supported above it on two steel pillars. The valve gear is peculiar; there is a steam-moved main or distributing valve working horizontally and controlling the admission and exhaust of the steam to the cylinder ends, and an auxiliary valve, worked by a tappet gear, moving vertically on the back of the main valve and controlling its movements while also serving as a cut-off valve. The main valve is an ordinary slide valve, hollow, cylindrical at its ends, but D-shaped at its middle, where ports are formed, and it slides on a cylindrical face which is provided with the usual cylinder ports. The cylindrical ends fit into small cylinders or caps in the ends of the steam chest; the D-shaped part of the valve forms a flat face across which the auxiliary valve moves, and ports are formed in it leading to the ends of the main valve, and others admitting steam to the cylinder ports. The auxiliary valve is moved by a tappet lever driven from the middle point of the piston rod, and it admits steam alternately to the ends of the main valve thus causing it to move to and fro: the auxiliary valve also cuts off the steam at about 0·75 of the stroke, the remainder being performed by expansion. When starting or when otherwise necessary steam may be admitted during the whole stroke through by-passes cut in the main valve and its caps; these are opened by rotating the caps from outside the valve chest. As the main valve must be at one end or the other of its stroke, the pump is always ready to start.

The water cylinder is double-acting; it has a gun-metal liner and the piston is packed with ebonite rings. The inlet and discharge valves are of the Kinghorn pattern (*see* No. 344) each having three discs with a spring and guard above; they are arranged one above the other and their seatings and guards are held in position by a single screw above. The pump has a steam cylinder 3 in. diam. and a water cylinder 3·5 in. diam., the stroke being 6 in.

It is capable of delivering 700 gal. of water per hour when working at 31 double strokes per min. M.3520.

634. Diaphragm pump. Presented by Messrs. Ham, Baker & Co., Ltd., 1912.

The diaphragm pump, which is a particular form of the primitive bellows pump, was invented in France in 1732, but is possibly of still earlier origin. The principle of its action is that a flexible disc, held around its edges to the pump chamber, is caused to rise and fall so as to vary the volume of the chamber just as a piston does in a cylinder. Its advantages are that it will pump water containing solid matter in suspension, that it has a large capacity, and that it is simple in construction.

In the pump shown the body has an inlet, with a check foot valve to attach suction hose. Between the pump body and the top with the discharge lip is clamped a corrugated diaphragm of india-rubber with a hole in the middle, which acts as the seating for a delivery clack valve. Around this valve are top and bottom rings attached to a crosshead above. The latter is actuated by a lever, the fulcrum of which can be either right-handed, left-handed or facing the discharge lip, as found most convenient. In place of the lever, a belt or direct motor drive can be arranged.

The size shown is for 3 in. diam. suction and will raise 4,000 gal. per hour at a low lift; its weight is 182 lb. The pump is also made completely enclosed as a lift and force-pump for emptying cesspools, etc. M.4004.

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635. Model of water-pressure pumping engine (working). (Scale 1 : 12.) Made by T. B. Jordan, Esq., 1843.

This represents an engine in which the energy is supplied by water at a high pressure; it was constructed in 1842 at the Butterley Works, from designs by Mr. J. Darlington, and erected at the Alport Lead Mines in Derbyshire. These mines were drained by an adit level, three miles in length, which delivered into the Derwent all water within 132 ft. of the surface; the engine was then added to pump from the lower levels by means of water received from the rivers Lathkil and Bradford, the used power water being also delivered into the drainage adit. In 1852 the engine was removed to the Tarlargoch Mine in North Wales.

The cylinder is 50 in. diam. by 10 ft. stroke, and the piston-rod passes through the bottom of the cylinder and is directly attached to the spear rods which terminate in a pump plunger 42 in. diam. (*These intermediate rods, which are of wood, are dispensed with in the model.*) The admission and discharge valves for the power water are 22 in. diam. by 22 in. long, with feather edges; but there is also a pair of similar valves 5 in. diam., the object being to avoid concussion by closing the large valves when 0·875 of the stroke is completed, leaving the small ones only to be closed at the end of the stroke. The valves are actuated by a tappet motion driven by a rod connected with the top of the piston and guided by a link parallel motion. The supply water was under a head of 130 ft., and the pumps had a lift of 130 ft., the total efficiency of the plant being about 70 per cent.; the working speed was five double strokes per minute, and the discharge 600 gal. per stroke. M.1413.

636. Model of water-pressure pumping engine (working). (Scale 1 : 8.) Lent by Messrs. Hathorn, Davey & Co., 1888.

This is a pumping engine, by Mr. H. Davey, on the same principle as the preceding. Such engines are frequently employed where water at high pressure is available, as they are economical transformers under suitable conditions. They may be placed down in the workings of a mine without risk of stoppage that might take place by submergence with water.

In the example shown, internal packings are avoided completely by the use of plungers and external glands. The power plungers are in the middle of

the machine and stationary, being bolted to a central high-pressure valve box which corresponds with the valve chest of a steam cylinder. Upon these small plungers slide the two large plungers of the pumps. The pump barrels are bolted to the bed plate and the plungers are tied together by two long side rods. At the end of the pumps are their valve boxes, the delivery boxes being connected by a long horizontal pipe. The engine valves are of the vertical drop type, with the upper stems or guides acting as pistons. The water to and from these pistons is distributed by an auxiliary differential valve gear, worked by a lever connected with the main pumps. From the high-pressure valve box the water passes through the interior of one of the small plungers, so driving the large plunger along and into the pump barrel, the other large plunger making an out-stroke at the same time under the constraint of the tie rods, and also discharging the used high-pressure water displaced by the other small plunger. The valve gear then reverses and the return stroke takes place. The exhaust water from the engine may be turned into the delivery pipe of the pumps and so brought to the surface without further pumping, the power head in which case is only the difference between the two heads of water. M.1907.

637. Model of Riedler pump. (Scale 1 : 16.) Lent by Messrs. Fraser and Chalmers, Ltd., 1907.

The feature of this pump, which is of the differential plunger type, is that the valves are operated by mechanical means. This enables the pump to be worked at a higher piston speed than if the valves were moved, as is usual, by the liquid passing through them; it also minimizes concussion and obviates "slip." The arrangement is that patented in 1885 to 1891 by Professor A. Riedler.

The valves are of the annular type and have a high lift. They open freely with the help of springs, etc., but are closed, just as the end of the stroke is reached, by bent levers interconnected by an external rod, and actuated by a rod and eccentric on the crankshaft or by other means. To obviate the breakage that might result from inaccurate adjustment, the valve is made in two parts on a tubular spindle with a spring interposed so that a slight movement may take place after the valve has reached its seat.

The area of the outer end of the plunger is twice that of the inner end. When the plunger moves to the left the suction valve is closed and the delivery valve opens, and through it passes the full volume displaced. Half of this goes to the delivery main and the other half is drawn into the space left by the stroke substituting the large for the small part of the plunger in a chamber enclosing it. In the return stroke this latter half is displaced to the delivery main while a fresh quantity is being drawn in. Thus the advantages of a double-acting pump are obtained with only two valves. M.3475.

Pump Details.

638. Drawing of pump bucket. (Scale 1 : 4.) Presented by Messrs. G. J. Worssam & Son, 1904.

This bucket was used for a pump 18 in. diam. and 35 ft. lift, worked by an atmospheric engine designed by Smeaton in 1767 for the New River Co. at Clerkenwell. In it was employed the self-adjusting cup-leather packing which appears to have been introduced by Smeaton to replace the leather discs or rings previously used.

The bucket consists of an iron ring with a diametral bar across it, to which is secured a disc forming two leather clacks, each provided with strengthening plates; below this ring is the cup leather and a brass ring, fixed by set screws, which retains it. The lower end of the pump rod is opened into four prongs, which curve outward and are riveted into the main ring; this construction gives larger valves than are possible with a central rod, and also distributes the stress from the rod. M.3323.

639. Collection of models of pump valves. (Scale 1 : 12.) Made by T. B. Jordan, Esq., 1844.

Most of these are large valves intended for use in mine drainage pumps, in which single flap valves would be objectionable owing to the shock on closing through the high lift necessary to obtain the requisite area, and also to the intensity of the pressure upon the seating.

(*a*) This is a double clack or butterfly valve; the leather disc forms the hinges for two valves and also their working faces.

(*b*) This valve consists of six triangular clacks arranged in the form of a hexagon, the sides of which are formed by the leather hinges. It is a modification of the "bishop's cap" valve, introduced and extensively used by Boulton and Watt.

(*c*) R. Jenkyn's annular clacks. With the object of providing a large area with a limited movement, the valve is made of three concentric portions; the central clack is hinged to the annular one beneath it, and this to the lower one. These were patented in 1841.

(*d*) R. Hosking's many-seated valve. This is composed of a series of rings working on a vertical guide, each ring having its seating on the ring beneath it. The numerous seatings increase the discharge area with a limited lift, and concussion is reduced by the rings closing successively.

(*e*) N. Harvey and W. West's double-beat valve. This is a modification of the steam valve so long used in Cornish engines. The valve is in the form of a deep ring with a seat at the lower edge, and another seat of somewhat less diameter at the upper edge. As the fluid pressure only acts on the difference between the areas of these two portions, the blow on closing can be reduced indefinitely, while, on account of the two seats, the discharge area for a given lift is nearly double that of a simple valve. In the example the lift is limited by a central stop, which acts also as a guide; it was patented in 1837.

(*f*) J. Darlington's single-beat tubular valve. The valve is in the form of a short cylinder, the lower edge of which beds on an ordinary seating, while the upper portion slides on a central stem, the joint being made tight with metal packing rings. By this arrangement the valve is almost in equilibrium, while only one seat is employed.

(*g*) R. Hosking's double-beat valve is a modification of (*e*). The areas of the two seats are very unequal, so as to ensure rapid closing, and the valve is guided by three pins projecting from its under surface; these also limit the lift.

(*h*) G. H. Palmer and C. Perkin's elliptical clack. This is an elliptical disc turning on an axis that does not pass through its centre of gravity. The arrangement resembles the old form of throttle valve for a steam engine, and gives partial equilibrium, but does not provide for leakage through wear. It was patented in 1840.

(*i*) Beneath the bench is a full-sized model of a 20 in. double clack valve suitable for low-lift pumps. The seatings meet in a central ridge at an angle of 155 deg. by which device the angular movement of the clacks for complete opening is considerably reduced. The clacks are retained in position by loose hinges, having bushed bearings carried in lugs on the seating casting, and provision is made for securing leather to the valve faces.

For mining pumps, lifting dirty or sandy water, double-beat and other metal-faced valves are not so extensively adopted as they are where pure water only is dealt with; with many makers the tendency is to increase the number rather than the size of the valves employed. M.2653–4.

640. Buckets and rods for mine pumps. Received 1865.

In the example for a 10 in. barrel, the bucket is a ring casting with a central cross rib, through a hole in which the pump rod passes before being secured by a cotter below. Above the bucket the rod is spread out, to enable it to secure a leather disc which forms the two flap valves, each of which is strengthened by two metal plates. The circumference of the bucket is packed by a long leather sleeve which acts as a cup leather; it is secured and

strengthened below by a wrought iron band held in position by the rod cotter. A portion of the spear rod, together with the conical sleeve coupling by which the interlocking ends of the pump rods are held together, is also shown.

Two buckets 6 in. diam. are shown having leather flap valves, but in one case the bucket is packed circumferentially, in a non-adjustable recess, with marine glue or guttapercha as patented in 1844 by Mr. T. Heaton, while in the other a built-up leather cup is used.

In another example 6 in. diam. the valve is in two portions, a heavy ring and a collar, sliding on the pump rod so that two openings are obtained; the bucket is made tight in the barrel by soft packing which can be tightened by a screwed sleeve below.

In an example 5·5 in. diam. the arrangement is that patented in 1855 by Messrs. M. Kennedy and T. Eastwood, the bucket being packed circumferentially by a single spring ring and centrally by a solid ring which, alternately by the friction of the spring or the pressure of the water, is moved up or down through a travel of 0·5 in. at the ends of the stroke; the lower portion of the bucket serves as a seating and is only 4·6 in. diam. M.2731.

641. Pump valve. Presented by F. C. Haste, Esq., 1904.

This is a pump valve and box of the form patented by Mr. Haste in 1900. The valve, which is made of "dermatine," is of double conoidal shape and is contained in a box of similar form. It is free to slide axially upon a central spindle supported by webs, and, when closed, seats itself on the curved surface of the box. The water-way past the valve has an area equal to that of the inlet pipe, so that the lines of flow are but little disturbed. This example is arranged as a suction valve. M.3378.

642. Bramah's original hydraulic pump and press. Received 1857. Plate X., No. 5.

This is the machine constructed in 1796 by Joseph Bramah to demonstrate the principle of his hydraulic press. By exerting a moderate force on a small pump plunger, a certain fluid pressure is obtained which is transmitted to a cylinder fitted with a large piston, and so the force driving the large piston outward is greater than that exerted in forcing the smaller piston down, in the ratio of their areas.

The apparatus consists of a stout timber base carrying at one end a cistern, on which is fixed a brass cylinder and a small force pump which draws its water from the cistern and delivers it into the cylinder. A leather-packed piston in the cylinder extends upward to a strong lever which carries at its extremity a weight platform, the leverage being 20:1, so that 1 cwt. on the platform is equivalent to 1 ton on the ram. When the pump is worked, a load of 6 cwt. is lifted in the scales, showing an upward pressure in the ram of over 6 tons. There is a small hole on the side of the cylinder which permits the escape of the water if the piston is pumped too high, and a small valve is arranged that permits the water to return to the cistern when it is desired to lower the piston. The pump ram is 0·5 diam., and the piston 4 in. diam., so giving an area ratio of 1:64. The hand lever of the pump has two fulcra, but its maximum advantage is about 1:18, so that from the hand to the press the total ratio is over 1:1,000.

Owing to the difficulty experienced in boring out these closed cylinders when longer strokes were required, a turned ram, working through a leather collar or packing, was soon adopted, and has since remained the usual construction followed when employing hydraulic pressure. Inv. 1858–57.

643. Model of hydraulic pumping engine (working). (Scale 1 : 8.) Lent by Messrs. Sir W. G. Armstrong, Whitworth & Co., 1899.

When Lord Armstrong introduced his system of hydraulic machinery the pressure water generally used was obtained from the town supply

mains, which at Newcastle and several other places are under a head of 200 ft., *i.e.*, a pressure of 86 lb. per sq. in. Owing to the uncertainty of the supply, and for other reasons, water tanks or towers were added, while to give sufficient storage in a situation where the demand for power was very fluctuating, the well-known water tower at Grimsby was constructed, and is still in use, as a means of storing a large amount of water at a considerable head.

In 1851, Lord Armstrong "resorted to another form of artificial head which possessed the advantage of being applied at a moderate cost in all situations, and of lessening the size of the pipes and cylinders by affording a pressure of greatly increased intensity." This was the hydraulic "accumulator" (*see* No. 1073), which is a reservoir giving pressure by load instead of by actual head, and consists of a heavily weighted vertical ram of large area lifted by water forced into the cylinder by a pumping engine.

The type of engine first used for this service had a plunger pump at each end of the cylinder, but in the model a single plunger only is used, the work in the two strokes being distributed by the use of two heavy flywheels; two connecting rods are also employed to balance the stresses. Above the pump are two domes communicating with the suction and delivery pipes respectively, and containing strainers. In a later arrangement the combined bucket and plunger pump was arranged between the cylinder and the crank-shaft, while finally, at the suggestion of Mr. H. Thompson, the clack of the bucket was dispensed with and the valves confined to readily accessible valve boxes. M.3083

644. Model of a hydraulic press and pumps. (Scale 1 : 4.) Contributed by S. Perkes, Esq., 1866.

This represents a double-ended hydraulic press for extracting oil from linseed, cottonseed, or similar material; it embodies some arrangements patented by Mr. Perkes in 1860. The seed is placed in canvas bags which are stacked between recessed metal plates, and the whole mass is then compressed between a pair of opposing hydraulic rams, by the pressure of which the seeds are broken and pressed into a solid cake, the contained oil in the meantime descending into a collecting tray. The pressure is maintained so long as oil is escaping, and when the work is finished the material is in the form of a hard cake, from which the canvas bags are peeled off for further use; such cake is utilised as food for cattle.

The two hydraulic cylinders of the press are connected by three tie-bolts, which also act as supports for the frames containing the seed bags, while by the use of two rams both ends of the stack can be simultaneously worked at when charging or emptying the machine. The return stroke of such horizontal rams is usually accomplished by the aid of chains and hanging weights, not shown in the model.

The water, under high pressure, is forced into the cylinders by pumps worked by double-ended levers; in commencing to press, the largest pumps are used, as there is slight resistance, but as the pressure increases some of the pumps are shut off by valves, and a smaller quantity of fluid is delivered per stroke but at a higher pressure. The areas of the plungers of the finishing pumps are approximately as 1 : 2 : 3, but owing to the difference in their strokes the volumes they deliver are as 1 : 4 : 9. Inv. 1866–17.

645. Model of hydraulic pumping engine (working). Scale 1 : 4.) Made by the Hydraulic Engineering Co., 1895. Plate X., No. 6.

This represents one of the sets of pumping engines employed by the London Hydraulic Power Co. at their central stations. The service of mains is supplied with water from the Thames, which, after being filtered, is forced

by the steam pumping engines into the high-pressure mains; accumulators at the station somewhat steady the demand, and also adjust the speed of the engines to the rate of consumption.

The model has one high-pressure cylinder 5 in. diam., and two low-pressure cylinders 6·5 in. diam., working downward on a three-throw crank-shaft with cranks set at 120 deg. The piston-rod of each cylinder is prolonged downward to form a plunger 1·25 in. diam. working in a single-acting pump barrel secured to the standards. The stroke throughout is 6 in., and the pumps deliver 9 gal. per min. at a pressure of 700 lb. per sq. in. when running at 120 rev. per min. with a steam pressure of 80 lb. By the introduction of a crank and flywheel a definite stroke and expansive working are secured; the difficulty with the connecting rods is overcome by forking them so as to clear the plungers.

The later engines of this type differ from the model in having three cylinders of increasing diameters, giving three-stage expansion. The surface condenser is formed in the standards, as so frequently arranged in vertical marine engines. M.2746.

646. Diagrams of hydraulic power plant. Lent by E. B. Ellington, Esq., 1891.

These were used to illustrate a paper read by Mr. Ellington before the Institution of Civil Engineers in 1888, and show the machinery at the Falcon Wharf pumping station of the London Hydraulic Power Co.

There are four sets of pumping engines, each of 200 indicated h.p. of the vertical two-stage expansion condensing type (*see* No. 645).

Steam is supplied by four Lancashire boilers fitted with Vicars' mechanical stokers and a Green's economiser in the back flue. There are five large filters for cleaning the water before it is pumped, and the delivery mains are here provided with two accumulators, each having a ram 20 in. diam. by 23 ft. stroke, loaded with iron slag to a pressure of 750 lb. per sq. in.

Additional stations with similar but larger plants have since been erected at Millbank, Wapping, City Road and other places. M.2384.

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647. Model of organ blower (working). (Scale 1 : 8.) Lent by Edward Godfrey, Esq., 1913.

This represents a bellows for blowing an organ worked by a hydraulic engine supplied from the towns' water mains.

The bellows are of the type which has been known from remote times, consisting simply of a movable board, with a non-return valve, joined at the edges by flexible walls to a fixed board having an outlet. There are two of these worked alternately by a rocking lever actuated by the engine. They supply air to a similar but larger bellows above them acting as a reservoir.

The engine stop valve being directly connected with the reservoir by a rod, is controlled automatically by its rise and fall. It admits pressure water to a distributing valve, patented in 1891 by Mr. A. A. Watkins, actuated by tappets on a rod fixed to the piston-rod. This admits water to one end of the main valve which is of the differential piston type with its waist always open to pressure. The piston valve is thus forced to one end of its travel, distributing fluid to one end of the cylinder. The tappet then acting on the distributing valve opens the end space of the piston valve to exhaust, and, owing to the different areas of the two pistons, drives it to the other end of its travel. This will be clear from the sectional drawing adjoining.

These engines can work at pressures between 15 and 250 lb. per sq. in. and will supply air at from 6 to 12 in. water gauge. Inv. 1913–96.

648. Chinese bellows from Tientsin. Presented by Captain Laurence Archer, 1862.

This is an elementary form of double-acting air-pump, used by the Chinese as a bellows for blowing a smith's fire. As a substitute for a cylinder a nearly rectangular wooden box is employed, and is fitted with a lid by which the interior of the machine is rendered accessible. The piston is of wood, and is made fairly air-tight by packings of paper pasted on. At each end of the working chamber is an inlet valve, consisting simply of a stiff paper flap covering a hole on the inside. Similar valves are placed beneath the pump in the wooden delivery chamber, from which the delivery pipe passes to the fire. M.1833.

649. Model of ventilating pump (working). (Scale 1 : 6.) Received 1865.

This is an air-pump used in the mines of the Harz, and also in Cornwall, where it is known as a "duck-machine"; it is employed for ventilating the end of a level or other point which is not reached by natural draught.

It consists of a square wooden box partly filled with water, through the bottom of which a pipe, in communication with the level to be ventilated, passes up to within a short distance of the top and is there closed by a clack opening upward. Inside the fixed box is another of the same shape, closed at the top but open below, and reciprocated by a wrought iron rod attached to a cross arm on the main pump-rod. This piston has two clack valves on the top, opening upward, to allow of the egress of the foul air when it descends; as it ascends these two valves and the water seal prevent the admission of air except from the working face. M.2613.

650. Model of a blowing engine (Scale 1 : 2) at the Penydarren Iron Works. Received 1859.

The form of air-pump shown, for supplying air to blast furnaces, represents standard practice in the South Wales district from 1825 to 1850; the actual machine was used at Penydarren Iron Works (*see* Part II. of Catalogue).

The cylinder is vertical and double-acting; the piston rod is, by a parallel motion, connected with a cast iron beam driven by a horizontal crankshaft rotated by power. The suction valves are metal-supported leather clacks; they are arranged in three suction boxes on the top cover and are directly attached to the bottom cover which is supported on an open base plate to give access. Similar delivery valves are arranged in bottom and top boxes connected by a pipe which leads to the blast main passing out of the building containing the pump. The main has upon it a large spherical "regulator" or reservoir of boiler plate, sixteen times the volume of the cylinder, for damping out fluctuations in pressure and velocity resulting from the intermittent action of the cylinder. Such reservoirs are not needed in modern plants owing to the large capacity of the hot-blast stoves, etc. A weighted safety valve on the blast main limits the pressure, which was 2 to 3 lb. per sq. in. The cylinder is 8·5 ft. diam. by 8 ft. stroke; the piston speed was about 250 ft. per min. M.1753.

651. Model of a horizontal blowing engine (working). (Scale 1 : 8.)

This represents a large blast engine used at the Royal Saxon Smelting Works near Freiberg. It had one horizontal steam cylinder, which drove two double-acting blowing cylinders or air-pumps. Each pump had a crankshaft and a flywheel, and the steam engine acted on a crank that connects these two shafts. The air-pump valves, which are leather flaps swinging on vertical axes, were arranged in the covers of the air cylinders, with the delivery

valve boxes beneath. The four delivery pipes connect with a large blast main, carried in a trench below the floor; in similar trenches the steam and exhaust pipes of the engine were arranged. M.2761.

652. Air compressor with water piston. Lent by T. Hurry Riches, Esq., 1896.

The compressor shown is a "wet" one and was designed in 1875 by Mr. Riches for obtaining high pressure in a single operation. The admission and delivery valves are on the top of two boxes rising from the ends of a horizontal compressing cylinder containing water, while at the side of each of these boxes is a small mechanically moved valve by which a little water from an enclosing cup is admitted at each stroke to compensate for that carried away by the air. M.2960.

653. Model of an air compressor (working). (Scale 1 : 4.) Lent by Messrs. G. Scott & Son, 1891.

This shows a belt-driven "dry" compressor, in which the desired pressure is attained in two stages, and so resembles a reversed compound engine. It consists of a fixed vertical open-topped cylinder, provided with a suction valve below, and fitted with a plunger driven by a forked connecting rod from the crankshaft above. The plunger is water-jacketed, and also bored out internally so as to form a cylinder of a vertical stationary ram fixed to the main framing. This ram, which is hollow, serves also as the delivery pipe. The bottom of the plunger is provided with a valve opening upward, and a similar valve is fitted at the bottom of the fixed ram. During the up-stroke air is drawn into the cylinder through the suction valve at its base, and on the down-stroke this air is compressed and forced through the valve in the plunger into the interior of the same, where on the next up-stroke it is again compressed by the fixed ram, through the delivery valve, in which it is finally discharged from the pumps. The compressed air is delivered into the standard of the machine, which is utilised as a reservoir, the outlet being at the top. Circulating water, for cooling the air, is conducted through the water jackets of the plungers by two swinging pipes at the sides. M.2420.

654. Model of an air compressor (working). (Scale 1 : 8.) Made by the Ingersoll-Sergeant Drill Co. Received 1904.

This is a steam-driven "dry" air compressor specially designed for supplying air to mining machines, and was patented by Mr. H. C. Sergeant in 1890.

The steam cylinder is placed near one end of a box bed, and is provided with a Meyer expansion valve, by which the cut-off can be varied from 0·2 to 0·75 of the stroke. The air cylinder is placed at the other end of the bed, and the two piston rods are secured to a block to which is attached, by a central pin, a wide crosshead free to adjust itself angularly and laterally. From the ends of this crosshead, return connecting rods drive crankpins fixed to a pair of flywheels mounted on a transverse shaft behind the steam cylinder, and on this shaft are fixed the eccentrics, which drive the valves through rocking levers; the engine is controlled by a centrifugal governor acting on a throttle valve.

The air cylinder has water-jacketed walls and ends, while its piston is hollow and has the piston rod attached to one face, while from the other projects a hollow tail-rod forming the air inlet. In each face of the piston a circular channel is turned which communicates with the interior and is fitted with an annular valve of T section, seated on the edge of the channel; these valves are inlets, and during the stroke of the piston one remains closed by the pressure while the other is admitting air behind the piston. The delivery

valves are contained in chambers in the cylinder covers, and are closed by springs; the valves are inserted from outside and the chambers are connected with the delivery by ports in the cylinder casting.

The steam and air cylinders are 14 in. and 14·25 in. diam. respectively, and have a stroke of 18 in. The machine runs at 120 rev. per min., has a capacity of 380 cub. ft. of free air per min., and may be used to compress air to pressures of 50 to 100 lb. per sq. in. M.3320.

655. Air compressor and separator. Made by Messrs. Peter Brotherhood, Ltd. Received 1910.

This is a compact form of three-stage dry compressor such as is used in torpedo work. It is of the form patented by Mr. P. Brotherhood in 1893.

The first two stages of the compression are performed in a cylinder 5·25 in. diam. by 4 in. stroke, fitted with a piston having a trunk 4·37 in. diam., extending through a stuffing box in the bottom cover. The upper part of the cylinder is thus of much greater capacity than the lower part. Air is admitted through an annular valve in the top cover, and is compressed on the up-stroke of the piston; it then passes, through valves in the piston, to its lower side, and is compressed a second time on the down-stroke. The third stage is performed in two plunger pumps, 0·75 in. diam., placed on either side of, and close to, the main cylinder; the air passes from the delivery valves of these, to a receiver, through a coil of piping enclosed in a water jacket, surrounding the air cylinders. Water is circulated in the jacket to abstract the heat generated by compression. Relief valves are fitted to the cylinders to prevent excessive pressures. The compressor is driven by two steam cylinders 3 in. diam. by 4 in. stroke, placed one on each side of the water jacket. The rods of the steam piston and of the air-pump plungers are all attached to one crosshead, with a single connecting rod extending to a crankshaft below; to flanges on it are bolted two flywheels, with eccentric pins on the outside for driving the steam-distributing slide valves. The cylinders are supported from the bedplate by three columns, one of which serves as a guide for the crosshead. The pump for circulating the cooling water is fitted to the outside of the water jacket, and its plunger is also driven from the crosshead. The air is compressed to about 1,700 lb. per sq. in.

The air after leaving the compressor is passed through a separator in order to remove any water that it may contain. The one shown, which is arranged to discharge automatically the accumulated water, was patented by Mr. P. Brotherhood in 1895. It consists of a long cylindrical chamber of small diameter, fitted with a head to which the inlet and outlet pipes, and also a pressure gauge, are attached; the lower end is closed by a cap fitted with a drain valve. Inside the chamber is a long bucket suspended from a rod which is held up against a stop by a spring; the upper end of the rod is formed as a piston valve, working in a cylinder bored in the head of the chamber, and normally closing the discharge orifice. The compressed air enters by a pipe directed downwards into the bucket where the water is deposited, while the air passes off by an outlet at the top. When sufficient water has accumulated, its weight overcomes the spring, draws down the piston valve and allows the water to discharge itself through a central tube reaching to the bottom of the bucket. Should the valve stick, it can be released by a blow upon the spring-retained stop at the top. M.3729–30.

Rotary Pumps.

656. Model of rotary pump (working). (Scale 1 : 4.) Presented by A. Siebe, Esq., 1872.

This garden pump, patented in 1828 by Messrs. H. Marriott and A. Siebe, has a small cylinder revolving concentrically inside a larger one; as it revolves

sliding blades or tongues in it are carried round and draw water in from the suction pipe, which opens into a large cylinder just beyond the point of contact of the cylinder with a curved fixed block inside the large cylinder; the water is forced out at the delivery pipe, which opens out from the large cylinder just before the point of contact with the fixed block. The outer ends of the blades are kept in contact with the casing by a fixed cam inside the revolving drum. M.1273.

657. Model of Fabry's ventilator (working). (Scale 1 : 12.) Received 1859.

This form of pressure blower, introduced in 1850 by Auguste Fabry, is used as an exhauster at some of the Belgian coal mines; it has been made of considerable size.

The casing is of masonry, lined with cement, strickled off by the revolving blades where a close fit is required. There are two horizontal axles geared together equally, and each carrying three radial blades of such length that their paths intersect. Air from the mine enters the lower part of the masonry chamber and is scooped outward and upward by the blades. As the blades overlap at the centre they do not carry inward from the atmosphere so much air as they exhaust from the mine, but to prevent air flowing in by this course the blades are provided with transverse blades each terminating in a curved contact piece. These six contact pieces on each revolver between them keep the central passage closed, but the volumes between the radial and the cross blades carry in a quantity of air that detracts from the efficiency of the arrangement; by filling in these volumes the machine becomes a three-lobed example of Roots's blower (*see* No. 661).

Fabry's ventilator was usually made with arms 4 ft. long by 10 ft. wide, and ran at 40 rev. per min.; it is stated that 14 h.p. was required to deliver 25,000 cub. ft. per min., under a resistance of 1·7 to 2 in. of water, and that the total efficiency was about 50 per cent. M.2615.

658. Model of Lemielle's ventilator (working). (Scale 1 : 12.) Received 1865.

This represents a form of rotary air-pump introduced by M. T. Lemielle in 1852 for mine ventilation; in practice, however, the machine was arranged with its axis vertical instead of as here shown.

It consists of a cylindrical casing having within it a revolving drum of smaller diameter on an eccentric axis, so that the drum touches the cylinder along one line. Two opposite segments are cut from the drum and replaced by flaps hinged to it along the leading edges; the trailing edge of each flap is connected by a link with a fixed pin that is on the axis of the cylindrical casing, so that this edge of the flaps is retained in contact with the casing. Each flap is kinematically a link in a separate four-bar motion. The air enters by an orifice on one side of the line of contact, and, being carried round by a flap, is forced out through a similar passage on the other side, the volume discharged by each flap per revolution being that of the crescent-shaped space outside the drum—less leakage and a deduction for the unused portion of the horns of the crescent; a modified form of the machine and three flaps.

In an actual example the casing was of masonry 14 ft. diam. by 7 ft. high; the fan made 37 rev. and delivered 25,000 cub. ft. per min. M.2616.

659. Sectional model of Beale's exhauster (working). (Scale 1 : 8.) Made by Messrs. Bryan Donkin & Co., 1892.

This model shows a form of rotary pump, patented in 1857 and 1866 by John Beale, which is extensively adopted for pumping gas. It consists of a flanged casing resembling a cylinder, bored out to a section which is not circular but is obtainable from the cardioid curve. This casing contains a

cylindrical drum, terminating in a shaft passing through the end cover and by which the drum can be rotated, while at the other end the drum is guided by a circular recess, in which it works, in the other cover. The axis of this drum is at the focus of the cardioid, so that a diametral plate projecting through the drum is always in contact with the casing at each extremity, although it is being carried round by the revolving drum. This plate forms the piston of the machine, and its middle is formed into two guides, between which slides a block fitted on a stud projecting from the end cover—this fixed stud thus giving the radial motion, independently of the guiding action of the casing.

The gas inlet is near the bottom of the casing on one side, and the outlet on the other, while the drum fits closely to the bottom of the casing, so as to prevent the return of the fluid pumped. These machines are made of large size, some delivering 6,000 cub. ft. when making 60 rev. per min., but a small one for 80 cub. ft. would make 300 rev. per min. M.2470.

660. Roots blower (working). Received 1876.

This is a small blower, with revolvers 3·5 in. diam. It resembles No. 661, except in the construction of the revolvers, which in this example have circular ends, each subtending an angle of 90 deg., and the waists also are largely circular.

There is probably more friction with this arrangement, and some unnecessary churning of the air, so that the makers now chiefly employ the form shown in No. 661. M.2730.

661. Roots blower. Lent by Messrs. Thwaites Brothers, 1890.

This machine is a rotary air-pump first patented by Mr. J. D. Roots in 1866, and is extensively used for supplying the air blast to foundry cupolas, smiths' fires, etc. The internal revolvers resemble pinions with only two teeth, and at each revolution discharge a volume of air equal to that of the portions of the teeth outside the pitch circles. To keep the revolvers in their true positions a pair of equal spur wheels is fitted to the shafts outside the casing. The bearings consist of a phosphor bronze cone keyed on the lower shaft, and a cast iron gland cone fitting in the end plate of the blower. The wear of the conical journals is taken up by closing in the end glands which act as bearings. The machine is arranged to take in its air through the perforated screens at the top and to deliver through the flanged outlet below; when so running the revolvers at the centre are moving upward. This size will deliver 460 cub. ft. of air at 350 rev. per min. M.2300.

662. Sectional model of Roots blower (working). Presented by Messrs. Samuelson & Co., 1890.

The revolvers of this small example are of the latest shape proposed by Roots, and, with the object of preventing the loss through leakage, are so formed as to obtain a double contact during certain portions of their revolution. The tips of the revolvers only touch the casing and are not used in forming the central contact, the concave portions being deeply recessed, so that the accumulation of grease or dirt in the hollows shall not cause thumping or unnecessary straining. The large central waist here adopted is to give increased strength at this section. Some of these machines have been worked up to a pressure of 15 lb. per sq. in. M.2305.

663. Sectional model of Baker's blower (working). Scale 1 : 8.) Lent by the Baker Blower Engineering Co., 1890.

In this blower, introduced in 1873 by Mr. J. G. Baker, there are three revolving axles. The upper one carries a drum with two projecting radial

blades, while the lower ones carry drums which form abutments. These abutment drums revolve at twice the speed of the upper drum, and are extensively cut away so that they can clear the blades well as they come round; while at other times they form complete abutments, preventing the passage of air between the casing and the upper drum. The drums are kept in their correct relative positions by external spur gearing. The air enters at one side of the machine, and is carried round the top by the blades to the outlet on the other side, where it is discharged under pressure. M.2339.

664. Rotary pump (working). Lent by Messrs. R. A. Lister & Co., 1894.

This is a small example arranged for driving by belting. It consists of a short cylinder enclosing a cylindrical drum, so carried in bearings that its axis is parallel to that of the enclosing cylinder. The internal drum is in contact with the cylinder at the top, and the suction and delivery orifices open into the cylinder on opposite sides of this line. The drum is cut through by a diametral slot, into which are fitted two blades, mutually forced outward by an intervening spring. As the drum is rotated the blades are kept in contact with the enclosing cylinder, and with the drum divide it into three chambers of varying capacity. The delivery is practically continuous. M.2689.

665. Rotary blower (working). Received 1900.

This is a small example of a power-driven machine for forcing air under a pressure of a few inches of water, such as is required for a smith's hearth; it was patented in America in 1888 by Mr. L. C. Crowell.

It consists of a cylindrical casing, having within it a drum placed eccentrically so as to touch along a line, on opposite sides of which are the admission and discharge ports. The drum has four radial slots fitted with plates, which, as the drum is revolved, are pressed against the casing by springs, so that the crescent-shaped chamber is always divided into four or five compartments. The edges of the blades are packed with strips of vegetable fibre. M.3099.

666. Rotary pump (working). Lent by R. Johnson, Esq., 1891.

This "drum" pump, which was patented in 1890 by Mr. Johnson, resembles in its mechanism Joseph Eve's steam engine of 1825. It has two revolving prisms on parallel axes which are compelled to rotate within a casing at equal speeds by external spur wheels. The lower revolver is in the form of a cylinder with two projecting ribs or blades, and the upper revolver is a larger cylinder with two recesses which allow these blades to pass. The inlet is on one side of the casing, and the discharge orifice on the other. It is intended that the loss by eddying shall be minimised owing to the continuous course of the flowing water, the lower revolver acting as a piston and the upper one as an abutment. Such pumps have been worked against a head of 180 ft. The small example shown is intended for running at 300 rev. and delivering 12 gal. per min. M.2412.

667. Rotary pump. Lent by Messrs. Fraser and Chalmers, Ltd., 1904.

This pump is of the type in which a drum with sliding blades revolves eccentrically within a chamber. In the belt-driven example shown the chamber is, however, in halves, each less than a semi-circle, as patented in 1897 by Mr. R. L. Gurden, and springs are employed to force out the radial blades or pistons so that they shall remain in contact with the walls of the

chamber. In another modification by Mr. Gurden, dovetailed recesses are left in the walls of the chamber for the reception of babbitt metal which can be poured into them and around a core of the required outline so as to obviate machining. M.3338.

668. Rotary pump (working). Presented by the Albany Engineering Co., 1906.

This is a rotary pump consisting of two spur wheels geared together and rotating inside a closely fitting casing. The water enters at one side of the wheels and is carried round the casing and discharged at the opposite side. The method used for preventing leakage was patented in 1904 by Messrs. H. Handoll and R. J. White. Grooves are formed along the edges of the teeth and across the faces in contact with the end covers; these grooves become filled with water which acts as packing. The axles run in plain bearings formed in the end covers and the driving axle passes through a stuffing box.

The example shown will raise 500 gal. of water per hour to a height of 100 ft. when running at 430 rev. per min. M.3434.

Centrifugal Pumps and Fans.

669. Original wheel of the Whittlesea Mere centrifugal pump together with drawing (Scale 1 : 24) of the complete plant. Presented by Messrs. Eastons and Anderson, 1877.

This early application of the Appold centrifugal pump was made by Messrs. Eastons and Amos in 1855 to drain Whittlesea Mere in Huntingdonshire. The scheme affected an area of 6,600 acres, and was the largest pumping installation undertaken up to that time; the machinery remained in use till 1877, when it was replaced by a larger plant.

The pump had no casing, as the wheel worked submerged in a cast iron coffer-dam; the water entered this by a bell-mouth at each side, and, after passing through the wheel, was delivered between two diverging discs, which utilised some of the whirling velocity of discharge. The action of the revolving wheel caused the water to rise in the dam until it escaped at the top at the higher level.

The wheel has a central disc and boss of cast iron, while there are two parallel side discs of copper. These are all connected by copper blades of the curved type introduced by Mr. J. G. Appold in 1851, and to which the efficiency of the pump is largely due. The wheel is 4·5 ft. diam. by 15·5 in. face, and weighs 933 lb. It was directly driven by a horizontal steam engine of 4 ft. stroke, and at 90 rev. per min. delivered 15,000 gal. (*i.e.*, 67 tons) of water per min. against a head of 4 or 5 ft. M.1732–3.

670. Centrifugal pump. Contributed by Messrs. Eastons and Anderson, 1876.

This is an Appold pump embodying details patented in 1862 by Mr. J. C. Amos.

The casing is of the spiral or volute form with cover bolted on for convenience of access to the wheel in case of fouling. The suction pipe divides into two branches so as to deliver on both sides of the wheel at its axis in order to balance end thrust. The wheel is enclosed by side discs; the vanes are of the curved form determined experimentally in 1849 by Mr. J. G. Appold as being more efficient than the simple radial form. The example has suction and delivery pipes 8 in. diam. and a wheel of 14·5 in. diam.

M.1432.

671. Model of centrifugal pump. (Scale 1 : 8.) Lent by Messrs. Lawrence and Porter, 1876.

This represents a centrifugal pump with 6 in. pipes. The wheel is of the double disc type and is enclosed in a spiral delivery chamber, the suction entering the discs at the centre from each side. To facilitate the removal of the wheel, and also to simplify the general construction, the pump case on one side is formed with a flange, on to which a closing cover is bolted, as patented in 1875 by Messrs. J. E. Lawrence and E. V. Porter. This cover can be removed without disturbing the suction or delivery pipes or removing the spindle. M.2515.

672. Wade and Cherry's centrifugal pump. Lent by J. A. Wade, Esq., 1890.

In the ordinary centrifugal pump the distance passed through by the water while it is under the action of the blades is very limited, so making it difficult to establish the necessary rotary motion without wasting energy through too violently changing the velocity of the water. To obtain a more gradual action the pump shown has the usual wheel, but in addition helical blades are provided which extend into the two branches of the suction pipe, and form extensions of the wheel, as patented in 1884 by Messrs. J. A. Wade and J. Cherry. By these considerable velocity is gradually given to the water before it reaches the wheel, thereby reducing the usual shock on entering. It is stated that these helical blades reduce the speed required for pumping, and that they increase the suction head that the pump will work upon.

The example has pipes 6 in. diam., and a wheel 17 in. diam. M.2293.

673. Model of centrifugal pumping plant (working). (Scale 1 : 8.) Lent by Messrs. J. and H. Gwynne, 1894.

This shows a horizontal compound condensing steam engine driving directly a pair of centrifugal pumps, four sets of which, together with 10 horizontal boilers, were erected in 1874–6 to drain the Ferrara Marshes, in Northern Italy. The plant discharges 2,000 tons of water per min., to a maximum elevation of 12 ft., each of the eight pumps having a capacity of 56,000 gal. per min. It is stated that the fuel consumed is 2·5 lb. per indicated h.p., and 4 lb. per water h.p., which is equivalent to a duty of 55 million ft. lb. per cwt. of coal.

The steam cylinders are 27·7 in. and 46·6 in. diam. respectively, with a stroke of 27 in., and the cranks are at an angle of 130 deg. Both cylinders are steam jacketed, and the high-pressure cylinder has an expansion valve fitted on the back of the main valve. The exhaust steam passes into two tubular condensers fixed in the delivery pipes, the whole of the water pumped passing through these condensers, which have tubes 3 in. diam. and 750 sq. ft. of tube surface. To clear the condensers a vertical air-pump, 19 in. diam. by 12 in. stroke is provided, and driven by an eccentric situated between the two cranks. The pump wheels are 60 in. diam., and the pipes 54 in., the volute casings of the pumps being 15 ft. diam. in single castings. The sluice gates are worked by hydraulic pressure applied by vertical cylinders. Each of the 10 boilers has 730 sq. ft. heating surface and 30 sq. ft. grate area. M.2567.

674. High-lift turbine pump. Made by Messrs. Mather and Platt, Ltd., 1908.

This is a two-stage centrifugal pump of the type patented by Prof. Osborne Reynolds in 1875. High speed centrifugal pumps with a single wheel can be made to run efficiently under heads of 100 ft., or even more, but when greater pressures are required, multiple pumps must be used in which

several wheels, each working in a separate chamber, are arranged in series on a shaft. The delivery water from one wheel has its kinetic energy converted into pressure energy by passing through expanding passages in the surrounding casing, and is then led to the next wheel where its pressure is further increased.

The sectioned example shown, which has two wheels, is built up of three main castings bolted together. The first of these forms the bedplate and has cast with it one end cover and the water inlet; the second part is a disc containing the expanding guide passages which lead the water from the periphery of the first wheel to the centre of the second one; these passages take a spiral course so that the water is nowhere forced to undergo any sudden change of direction. The lift of the pump may be increased by inserting other similar discs with the corresponding wheels. The remaining portion of the casing forms the other end cover and the water outlet. The wheels are keyed to the shaft and are designed so that end thrust is eliminated; renewable bushes are fitted where the wheels are required to run water-tight in the casing. The shaft is fitted with gunmetal sleeves where it passes through the stuffing boxes in the end covers. The bearings are formed in separate castings bolted on, and a ball thrust bearing is placed at the end of the shaft. A funnel and pipe are provided for filling the pump when starting. Owing to the high speed of these pumps, they are most conveniently driven by being directly connected with electric motors.

The pump has suction and delivery pipes 3 in. diam. and wheels 6 in. diam.; it is capable of delivering 75 gal. of water per min. against a head of 240 ft., when running at a speed of 1,820 rev. per min.; with a larger number of stages it would work against a head of 350 ft. M.3555.

675. Model of ventilating fan used in the Saxon mines (working). Received 1865.

This is a small fan, with five radial arms and flat rectangular blades, which revolves within a casing about 4 ft. diam. The air is taken in at the centre of each side by a pipe 20 in. diam., and is discharged at the circumference through a rectangular tube 15 in. by 10 in., to be conveyed through wooden or zinc pipes to the working face. The fan is driven by a belt kept tight by a tension pulley, and makes 16 rev. for one of the driving wheel.

A similar fan used in the Saxon mines had blades 8·5 in. sq. and a diameter of 2·5 ft. It could be driven by one man at 400 rev. per min.; the pipe was 6 in. sq. and 60 cub. ft., *i.e.*, the estimated quantity required by ten miners, were drawn by it from a distance not exceeding 440 yd. M.2614.

676. Exhausting fan.

This is a small centrifugal fan arranged for driving by belting. The air enters the fan through two passages formed in the base, and is delivered between the two enclosing side plates. The fan consists of a central disc from which project on each side eight blades, curving backward. M.2783.

677. Model of ventilating fan. Received 1902.

This fan is of the centrifugal type, and embodies details patented in 1887 by Mr. N. Chandler; it has blades, slightly S-shaped, projecting from the sides of a central disc on a spindle carried in bearings placed outside the sheet steel casing, by which the air is led, from passages below communicating with the mine, into each side of the fan, thus avoiding end thrust. A volute casing and expanding outlet cause some of the velocity energy of the air on leaving the blades to be converted into pressure energy. An actual plant of this construction, with an engine, such as No. 132, having cylinders 16 in. and 24 in. diam. by 16 in. stroke, driving a fan 15 ft. diam. by 6·5 ft. width, at 151 rev. per min., indicated 117 h.p., and passed 173,000 cub. ft. of air per min., against a pressure of 3·1 in. of water. M.3262.

678. Sirocco fan. Lent by Messrs. Davidson & Co., 1901.

This construction of centrifugal fan was introduced in 1898 by Mr. S. C. Davidson, as the result of a series of experiments made with the object of reducing the eddies which he considered existed near the after face of blades of the ordinary type.

The "Sirocco" fan has usually from 32 to 64 blades, of a radial length of from 0·1 to 0·06 of the diameter of the rotary portion, and an axial length of 0·6 diam., thus forming a hollow cylinder which has a disc and shaft at one end while the other end is completely open for the entrance of the air. The fan is arranged in a spiral casing of rectangular section, carrying on one side the open frame containing the bearings. The blades are made from sheet metal stampings, pressed to shape, and are riveted to the end disc and a connecting ring. Their acting faces are concave, and so set that they scoop in the air and deliver it tangentially with a velocity that is estimated to be 1·8 times that of the periphery of the fan. To this innovation is probably due the relatively high pressure given by the fan when compared with its speed.

The example shown has a fan of 5 in. diam., but an adjacent photograph represents a similar fan of 35 in. diam. directly driven at 450 rev. per min. by an electric motor. The output is stated to be 23,000 cub. ft. of air per minute, against a water gauge pressure of 1·5 in., with a consumption of 9 electrical h.p. Another photograph shows a larger fan, directly driven by a steam-engine, and supplying forced draught to a marine boiler working with closed ashpits. M.3191.

679. Air propeller. Lent by the Blackman Air Propeller Ventilating Co., 1890.

This machine is specially intended for moving large quantities of air against a slight resistance as required for ventilation, drying, etc.; it operates by a scooping action, and passes its air parallel to the axis of the machine, thereby greatly differing from a centrifugal fan. The form of the eight sheet-metal blades is such as to give about 70 per cent. more collecting than delivering area. To ensure the true alignment of the two bearings, they are carried in spherical sockets.

The example shown is 18 in. diam., and is intended, when running at 1,200 rev. per min., to deliver 4,000 cub. ft. of air, but similar propellers are made up to 7 ft. diam., with a delivery of 100,000 cub. ft. M.2295.

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680. Model of air filter. (Scale 1 : 5.) Lent by H. R. Witting, Esq., 1912.

For ventilating purposes and in many industrial operations air free from dust is required and may be obtained by filtering. The distinctive feature of the filter shown is that it is built up of a number of pockets of manageable size arranged in parallel, so that any one may be withdrawn, without disturbing the rest, for cleaning or repairs.

The unit consists of a wedge-shaped wooden frame. Over this is drawn a cotton filter bag with a pad around the opening whereby a joint can be made with the partitions in the main frame when the pocket is forced into position and expanded by the special angle clasps and bolts shown, as patented in 1911 by Messrs. K. & Th. Möller of Brackwede, Westphalia. The free ends of the pockets are kept apart top and bottom by distance pieces.

In the plant shown the filter is built into a masonry chamber, divided into two compartments by the main frame. In other situations, the pure air pipe is joined to the filter by a flange. The filter, protected by a suitable casing, can then be placed anywhere inside or outside a building, provision being made for a platform for use when withdrawing pockets for cleaning, etc., which may be done by a vacuum cleaner or otherwise.

The plant shown contains ten pockets and is capable of dealing with 2,700 cub. metres of air per hour (*i.e.* 1,600 cub. ft. per min.). M.4122.

Hydraulic Rams.

681. Hydraulic ram. Lent by John Blake, Esq., 1889.

In the modern example shown the supply water is allowed to flow through a drive pipe and escape valve until a considerable velocity is attained which causes the valve to close suddenly; the momentum of the arrested water causes a large rise in pressure sufficient to overcome the required head. An air vessel is introduced to moderate the pressure and to give a more regular discharge through the delivery pipe.

The ram consists of a cast iron box with the water inlet at one end and the escape valve at the other; the delivery valve and air vessel are mounted on top. The escape valve in this example is constructed in the manner patented by Mr. Blake in 1889. It consists of a vertical square box, with perforated concave sides, which fits into the base of the ram. A number of india-rubber bands are sprung over this box, the concave sides leaving some space between the grid and the rubber. The drive water rushes through the perforations, and runs to waste through the central outlet, until its velocity is sufficient to carry the rubber with it and so close the valve. The consequent rise of pressure forces some of the arrested water through the delivery valve into the air vessel and delivery pipe. Four stops, adjustable from outside, are provided, by which the distance between the rubber bands and the sides of the box can be varied to suit the water supply.

This ram has a drive pipe 5 in. diam. and a delivery pipe 1·25 in. diam. It is suitable for working with a fall of from 6 ft. to 20 ft. and a drive pipe from 30 to 300 ft. in length. With a head of 6 ft. it will raise 6,500 gal. a day to a height of 40 ft., or, with a head of 20 ft., it will raise 7,500 gal. a day to a height of 120 ft. M.2285.

682. Hydraulic pumping ram. Lent by H. P. Vacher, Esq., 1903.

This ram is arranged for utilising the energy of a stream of possibly impure water for pumping clean water from some other source.

The impulse portion consists of a lower casing with an attachment for a drive pipe, and a pulse valve of a form patented in 1898, by Mr. R. C. Green, in which a rubber disc with a central hole is suspended below a concave grating which serves as a seat. The drive water flows away through this valve until its velocity becomes sufficient to bulge the rubber on to the grating and thus close the outlet. Above this portion and in communication with the drive pipe is a vertical cylinder fitted with a spring-loaded piston, which is attached to the piston of a single-acting force pump arranged above it and combined with an air vessel. When the column of water in the drive pipe is suddenly stopped, through the closing of the pulse valve, the accumulated energy is largely utilised in performing the delivery stroke of the pump, which forces water into the air vessel, and also compresses the spring; when the shock has passed off the pulse valve opens, by its elasticity, and the return or suction stroke of the pump is performed by the helical spring. The pure water is admitted to the pump by a suitable suction pipe, and the delivery takes place continuously from the air vessel through a similar pipe. To prevent noise, the pump valves also are made of rubber. M.3310.

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683. Pulsometer. Lent by the Pulsometer Engineering Co., 1876.

This greatly improved form of Savery's pumping apparatus of 1698 (*see* No. 37) was invented by Mr. C. H. Hall in 1872. It lifts water by the partial

vacuum resulting from the condensation of steam in a closed chamber, and then forces up the water by the pressure of steam introduced into the chamber.

It consists of a casting forming two working chambers and a central chamber that acts as an air vessel. One chamber is taking in water while the other is discharging it, and thus a nearly continuous delivery is obtained which is further improved by the air vessel. The two working chambers unite at the top in a steam chest containing a ball valve which can roll to either side, and so stop the admission of steam to either of the two chambers. At the lower portion of each working chamber is a suction and a delivery valve for water, and the boxes of these valves are respectively connected with the common suction and delivery pipes. The two suction valves are arranged together, so that a single ball suffices for the two seatings, but at the lower end of the suction pipe a foot or retaining valve such as the Perreaux valve (*see* No. 617) and box (shown separately) is also usually added if the suction height is considerable. The great superiority of the machine over Savery's consists in its being automatic in its action, a result that is obtained by the sensitiveness of the steam ball valve. This valve, when closing one side, is so close to its other seating that the sudden rush of steam that takes place, as soon as all of the water has been sent through the delivery valve, pulls the ball valve on to the previously open port or seat. Steam then enters the other chamber and proceeds to drive out the water that has there been drawn up, while condensation proceeds in the opposite chamber, which therefore commences to fill.

In a later form economy in steam is effected by the "Grel" arrangement.

M.2516.

684. Water-lifting apparatus. Lent by Messrs. Körting Bros., 1888.

This apparatus for raising water, called the "aquapult," introduced by Mr. Körting in 1885, is, like the pulsometer, a practicable and successful development of the principle employed in a crude form by Savery in 1698.

In the aquapult, as in the pulsometer, a succession of strokes or pulsations effect alternately the drawing-in of water, through a suction valve, and its discharge through a delivery valve into a rising main. A conical valve at the top of the vessel or chamber admits steam at intervals; the valve closes automatically, and the steam in the chamber becomes condensed, forming a partial vacuum, which draws water through the suction valve into the chamber. Steam is again admitted by the opening of the conical valve, and, pressing upon the water, forces it out through the delivery valve into the rising main, this steam being then condensed, and so on. A little air is drawn in through a very small valve, while the water is drawn through the large valve; this air forms a partition between the water and the incoming steam, tending to protect the latter against immediate and premature condensation. A perforated injection pipe is provided to accelerate the condensation at the proper time.

M.1896.

685. Model of air-lift pump (working). (Scale 1 : 20.) Made in the Museum, 1903.

The fact that the pressure at the base of a column of water containing air, in bubbles or otherwise, is less than with a column of water of the same height was observed in 1797 by Löscher, but his experiments received no practical application till 1846, when Crockford applied the principle to the raising of petroleum from the wells of Pennsylvania. In France the apparatus, under the name of an "emulseur," was used in 1886 by Gondry for raising sulphuric acid, but the recent and more extensive adoption of the air-lift pump dates from about 1893 and is largely due to the labours of Dr. J. G. Pohlé and Mr. J. E. Bacon.

The appliance consists of a vertical pipe reaching below the surface of the water to a depth about equal to the height above the surface to which delivery is to be effected, and of a separate pipe by which air is discharged into the rising pipe at its lower end, thereby reducing the density of the column within it so that, by the external pressure, water is forced to the top and escapes with the air at the delivery end. The system has a low mechanical efficiency but has the merit of being able to deal with gritty water or with chemicals, and the cooling action of the expanding air may be an advantage. It has been found in practice that the depth of the air nozzle below the level of the water in the well should be about 1·5 times the height of the point of discharge above, but the arrangement will work with less submergence; in an artesian well in which the water when tapped rises considerably, this submergence is obtained without additional boring.

The model shows the general arrangement of a plant erected in 1893 at Zwickau, in Saxony, to supply a yarn-spinning mill. The water from a stream is allowed to flow into a brick chamber, in the middle of which is sunk a tube-well to give the necessary submergence for the pipes, and is raised by the air-lift into an open tank over the well; from this it flows by gravity into a service reservoir more than half a mile distant and 13·5 ft. lower. The submergence is 63 ft., the lift 45 ft., the rising main 7·5 in. diam., and the air supply pipe 5 in. diam. At a test in 1898 the discharge was 900 gal. per min., while the volume of air required, measured at atmospheric pressure, was 2·73 times this amount; the compressor, situated at the mill, delivered at 30 lb. pressure above atmosphere, and the efficiency, reckoned from the work done by compressor to that of the work done on the water, was 28·8 per cent.

In the model a simple nozzle is used for the air jet, but in the actual pump a special box, shown in the attached drawing, was found to be more efficient. In Mr. Bacon's construction of air-lift, the air-supply pipe encloses the rising main; in some other arrangements the air pipe is carried within the rising main, but this, although convenient, entails unnecessary frictional resistance.

M.3301.

INJECTORS AND OTHER INDUCED CURRENT APPARATUS.

When a current of air, water, or other fluid is moving through a mass of fluid at rest, some of the stationary particles are carried along by the stream, the internal friction and inter-mixing creating what is described as an "induced current." With suitable vessels and orifices, the mass of fluid carried away by the induced current may result in the formation of a partial vacuum within the vessel, or else, by the use of a diverging tube, the velocity conferred may be converted into an increase of pressure. The exhausting action of these currents was known as early as 1719, but the first useful application seems to have been made in 1803, when Trevithick caused the exhaust steam from the cylinder of a locomotive to pass up the funnel, thereby greatly increasing the steaming power of the boiler owing to the improved draught through the fires resulting from the reduction of the air pressure in the furnace. Many applications of the principle have been adopted since then, amongst which may be mentioned steam jet exhausters and blowers, while a large number of ventilators have been constructed in which the wind is used to remove vitiated air by the same action. One of the most recent applications of induced currents is found in the liquid fuel apparatus (*see* Nos. 391–2), in which a steam jet breaks a stream of petroleum into a fine spray and carries it with a suitable current of air into the furnace of a steam boiler.

If the inducing current is of water and acts upon some surrounding liquid the arrangement is known as a "jet pump"; such a machine was used by Prof. James Thomson to lift water from a marsh by the energy in a running stream. In the fire-hydrant of Mr. Greathead a jet of high-pressure water is similarly used to give increased energy to a stream of water discharged from a low-pressure main.

The most useful and interesting apparatus of this class is, however, the injector boiler feeder, invented by M. Giffard in 1858 and introduced into England in the following year (*see* No. 691). Although as a general water-lifting machine it is not at all economical, yet for boiler feeding, where the heat absorbed by the water is not lost, it is a perfect appliance, provided the feed water is not originally very hot. When the invention was first announced it was generally discredited, as it appeared impossible that a jet of steam could force itself, together with much additional water, back into the boiler from which the steam issued, the vastly greater velocity of efflux of steam particles than that of particles of water under the same pressure, being overlooked. It was soon after proved, however, that not only would the injector feed the boiler from which it received its steam, but it would feed a boiler working at a much higher pressure than that from which its steam was derived.

From 1867 to 1880 various proposals were made for working injectors by exhaust steam assisted by a little boiler steam; but

in the latter year Messrs. Hamer, Metcalfe, and Davies introduced the "split nozzle" injector for working entirely by exhaust steam, and since then this class of injector has been extensively adopted, although for high pressures an assisting jet of live steam is generally necessary. Many improvements in detail have also been made in both classes of injectors with the object of making their starting more certain, as considerable difficulty was at first experienced in getting them to commence working, particularly if any lifting had to be done; other improvements were made to insure the apparatus restarting should it momentarily fail. Although the injector is entirely relied upon for locomotives and for many stationary boilers, in the Navy, feed pumps are invariably used for regular work.

The "ejector condenser," patented by Mr. A. Morton in 1867 (*see* No. 698), is a form of exhaust steam injector in which the energy of the steam is used to carry the condensing water out of a chamber representing a condenser, and in this way maintains in the exhaust pipe a partial vacuum, which assists in propelling the piston in a similar way to a condenser of the ordinary type.

686. Model of a jet pump. Lent by Prof. James Thomson, 1876.

This form of pump was designed by Prof. J. Thomson for the drainage of land where a small quantity of water, with a moderate fall, is available; by the apparatus the water can be used to elevate a much larger quantity to a lesser head. The arrangement was brought to a practical success at Ballynure, Ireland, in 1852.

There are no moving parts, the machine acting by sending the driving water in a vertical jet downward through a hollow cone connected with the water to be lifted. The combined jet then enters an expanding tube by which the velocity energy is gradually converted into pressure sufficient to elevate the whole mass. There is a loss of useful energy in the arrangement which will be serious or otherwise according to the conditions.

The jet pump, while working, must always have its full supply of water, and so for varying demands is arranged to work intermittently when the supply is below the maximum. This is accomplished automatically by storing the driving water in a reservoir or tank, which, when full, rapidly empties itself by means of two siphons.

In the model the supply of driving water is in the upper tank, which, by the double siphon arrangement, is, when full, rapidly emptied into the lower overhead tank. From the bottom of this tank projects the jet pump, which delivers into a lower tank provided with an overflow. The water to be lifted by the inductive action of the jet enters by the india-rubber tube, the lower end of which is inserted in it. M.1768.

687. Steam jet pump. Lent by Messrs. S. and E. Ransome & Co., 1887.

The suction and delivery pipes are in line, while the steam jet is introduced by a side branch, as shown in the attached sectional drawing. The limit of the suction lift is stated to be about 25 ft. As a pump, such an apparatus is not economical unless use is made of the heat given to the water, as in feeding boilers, or where hot water is required. M.1863.

688. Model of chimney cowl. (Scale 1 : 8.) Presented by G. Moore, Esq., 1914.

This cowl, patented in 1877 by Mr. C. R. Stevens, acts as an induced current apparatus to increase the up-draught when the wind blows, whatever its direction, as may be shown with a tuft of cotton wool. The top of the cowl is in the form of two truncated cones, base to base, and above them is a concavely based cone. The latter in practice was found to be liable to damage from the chimney-sweeper's brush. Inv. 1914–70.

689. Model of Boyle's ventilator. (Scale 1 : 24.) Presented by Messrs. R. Boyle & Son, 1898.

This apparatus is a form of jet-pump, in which the inducing currents of air are due to the passing wind; these currents are so directed as to carry away with themselves, in their passage through the ventilator, a quantity of the vitiated air from within the building. Fresh air, to replace the air removed, enters the building from below the floor, but is delivered high above the floor level through vertical pipes, by which means the formation of cold draughts is avoided. The model has, in the inlet and outlet tubes, tufts of cotton wool, which will indicate the action of the ventilator when it is blown across.

The ventilator consists of a fixed metal casing with four vertical orifices, and within it are curved vertical guides, which leave spaces between them that directly communicate with the ventilating shaft from the roof of the building. The passing wind, in travelling between the external casing and the vertical guides, has an inducing action, while the formation of the guides is such that the direct entry of air between them is greatly restricted by the form of the passages. By this arrangement the exhausting action of the two or more acting passages is made to exceed greatly the opposite action of the remaining ones. M.3018.

690. Model of Cooper's ventilator. (Scale 1 : 16.) Presented by Messrs. Thos. Ash & Co., 1899.

This construction of fixed ventilator was patented by Mr. G. Cooper in 1893. Its exhaustive action is due to the readiness with which a moving stream of air will carry with it some of a surrounding mass of stationary air, provided that the contact is suitably arranged and the resulting stream properly directed.

The apparatus consists of an open vertical pipe surmounted by seven segmental transverse wings or shields, each having a segmental orifice between it and the one above it; these passages are somewhat tapering. From whatever direction the wind blows, the quantity of air exhausted from the apparatus exceeds that entering, the difference always creating an up-draught in the vertical pipe. M.3061.

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691. Giffard's injector. Contributed by Messrs. Sharp, Stewart & Co., 1864.

This is the original form of the injector, introduced by M. Giffard in 1858, for supplying the feed water to boilers without the use of a pump. Although now adopted generally, it was for feeding locomotives that the great value of the apparatus was first fully appreciated, and on such engines feed pumps have been entirely replaced by injectors. The construction of this machine is best shown in the succeeding example, No. 692. M.364.

692. Giffard's injector. Contributed by Messrs. Sharp, Stewart & Co., 1875.

This is a sectional example of an injector following very closely the arrangement described by M. Giffard in his original patent of 1858 for "Improvements in Feed Apparatus for Steam and other Boilers, which improvements are also applicable to the raising and forcing of fluid."

Steam from the boiler is admitted into the apparatus through the inlet marked "steam," and a supply of water is laid on to the other inlet marked "water"; the outlet at the end is for the passage of the water that is being forced into the boiler, while the "overflow" outlet is provided for the escape of any water or steam that may accumulate in the apparatus when it is working imperfectly, as when starting. The live steam passes through the annular space between the solid cone and the conical nozzle, and thus issues as a fine hollow conical jet, moving at a high velocity; the particles of steam drag with them some of the surrounding air, thus causing in the enclosing space a reduction of pressure, so that the supply water enters by the atmospheric pressure. When thus started the water continues to flow and the steam of the jet condenses within it, thereby giving it sufficient velocity to force its way through a check-valve into the boiler. The various nozzles of the apparatus are capable of independent adjustment, since if too much water be drawn in by the inductive action of the steam jet, the combined stream will not have sufficient velocity to force its way into the boiler.

The action of the injector is more fully realised when it is remembered that the steam from a boiler issues into the atmosphere with a velocity that may be fifteen times as great as that of a water jet from the same boiler; this steam may, however, be condensed in five times its weight of water, so that after the distribution of the momentum of the steam jet into the mass of the combined jet a final velocity more than double that of a simple water jet from the boiler is obtained. This high velocity energy is converted into pressure energy more than sufficient to overcome the boiler pressure, by the slight divergence of the combining or delivery cone, which acts as a Bernoulli tube.

M.364A.

693. Compound injector. Lent by Messrs. Körting Bros., 1885.

This construction of double injector was patented by Mr. E. Körting in 1873 and 1876. It consists of two slightly different Giffard injectors (*see* No. 692), arranged in series, so that the first, or lifter, feeds the other, or forcer, which delivers into the boiler. The delivery chambers of both lifter and forcer communicate with the overflow pipe by a three-way starting cock; the latter and the two conical steam valves are manipulated by a single hand-lever. When starting, the lever is moved through a part only of its travel, thus slightly opening the steam valves and at the same time opening both delivery chambers to overflow; the arrangement then readily lifts water by its steam exhauster action. The handle is then moved right over, so as to open fully both steam valves and close completely the overflow, after which the forcing injector feeds into the boiler.

M.1624.

694. Compound injector. Lent by the Hancock Inspirator Co., 1887.

This form of double injector was patented by Mr. J. F. Hancock in 1876–1877. It consists of two Giffard's injectors (*see* No. 692), arranged in series, so that the first acts as a lifter and the second as a forcer, an arrangement that facilitates starting. The forcer valve at the top admits steam to the second injector, and there are two overflow valves, the upper one when open allowing the water and condensed steam from the lifter to pass direct to the overflow. In a modification of the above by the same makers, all the valves are actuated by a single lever.

M.1849.

695. Exhaust injector. Lent by Messrs. Davies & Metcalfe, Ltd., 1902.

This is a sectioned example of the injector patented by Messrs. Hamer, Metcalfe, and Davies, in 1877–80, in which, by an important modification in the usual construction, self-starting is secured and the apparatus is enabled to work with the exhaust steam from an engine, instead of requiring live steam from the boiler.

The injector consists of a cast iron casing containing the usual three nozzles, the steam nozzle, however, being exceptionally large on account of the large volume of steam to be passed, and having a conical spike in its centre to assist in concentrating the steam. The combining nozzle is the leading feature, however, as it is split or divided into two parts over a portion of its length by an axial plane, and one of these parts is hinged to the main portion at its upper end, so as to become a movable flap. The combining and delivery nozzles are connected together, and the water supply orifice beyond them is rendered adjustable by means of a nut at the delivery end. The overflow pipe has a chamber with a partition across it, which forms a water seal, and so prevents the entry of air into the combining cone.

When starting, the steam and water escape freely into the overflow by the open flap, but when the combined jet acquires such a velocity as to be capable of feeding the boiler its exhaustive action becomes sufficient to close the flap, so that the water passes into the boiler through the delivery pipe.

These injectors will, with exhaust steam, feed against a pressure of about 75 lb. per sq. in.; if required to supply a boiler at a higher pressure, an extra steam nozzle, supplied with boiler steam, is added to assist in the work; or else a supplementary injector supplied with boiler steam is used, which takes the water, already heated and raised to a considerable pressure by the exhaust injector, along into the boiler. M.3255.

696. Exhaust injector. Lent by Messrs. Holden and Brooke, 1888.

This is a sectioned example of an injector patented by Messrs. Holden and Brooke in 1884, and is specially constructed and proportioned for working with the exhaust steam from an engine, instead of requiring live steam from the boiler. The principle is the same as that of the ordinary Giffard's injector (*see* No. 692), but the details are modified to suit the lower pressure of steam employed; the apparatus is, however, even more remarkable than the original form, since by it the exhaust steam forces the feed into the boiler against the full steam pressure.

A large annular conical nozzle is provided for the steam jet in consequence of the great volume of low-pressure steam. In starting, the steam and water escape freely by an opening in the combining tube and through a clack valve to the overflow; when this jet acquires the necessary velocity to enable it to enter the boiler, the accompanying exhaustive action causes the overflow clack to close. The injector is self-starting, as the overflow automatically opens when feeding ceases. M.1918.

697. Restarting injector. Lent by Messrs. Gresham and Craven, 1887.

This is an injector patented by Mr. J. Gresham in 1884–5, in which there is a fixed steam nozzle and no hand-controlled valves, the arrangement being automatic in its starting adjustments. This is accomplished by forming the combining cone as a separate piece free to slide in a bush, so that it acts as a valve of short lift. In starting, the mixed water and steam escape through the overflow until the mixture has acquired a velocity sufficient to enable it to enter the boiler; then the reaction forces the valve upward, thus closing the overflow.

In this construction the cones can be removed for cleaning without breaking any pipe joints, an arrangement introduced by Mr. Gresham in 1877. M.1848.

698. Ejector condensers. Lent by Messrs. A. F. Craig & Co., 1901.

These are sectioned examples of the original form of the modification of the injector introduced in 1867–69, by Mr. Alexander Morton, as a means of condensing the exhaust steam of an engine and at the same time obtaining a considerable degree of vacuum—the apparatus performing the duties of both condenser and air-pump.

The smaller specimen is a model of a condenser for a double-cylinder engine, the exhausts from which enter by separate side pipes into superposed cones, while the condensing water enters by an upper pipe and is delivered as a central jet, passing through the exhaust steam space and entering an expanding delivery pipe. The steam in approaching the jet has considerable downward velocity, and the momentum it thus introduces into the water carries the mass into the delivery pipe, where the velocity energy is converted into pressure energy. As, however, the pressure at the outlet is only that of the atmosphere, the lower pressure is much less, so that a partial vacuum is maintained. Within the water cone is an air-jacketed nozzle, by which a jet of live steam can be introduced for starting the apparatus.

The larger example shows a later form, in which an adjustable central jet of live steam does any lifting of the cooling water that may be necessary, or supplies the energy that may be required for an improved vacuum. A closed chamber and a hollow cone are also added, by which any portion of the combined jet which may be too feeble to pass into the diverging tube is carried back into the jet, to be again exposed to the exhaust steam; at the same time it checks the ordinary supply of injection water until the apparatus is again clear. M.3188.

699. Ejector condenser. Made by Messrs. Körting Bros. 1893.

This apparatus, patented in 1882 by Mr. E. Körting, is for a similar purpose as the preceding.

It consists of a series of nozzles discharging into an expanding tube as in the ordinary injector, but a large number of drilled holes pointing in the direction of the flow permits of a further addition of steam to increase the velocity. An internal sliding tube, adjustable by a hand-lever, permits of the covering of these holes when starting, and of their being set in the position of maximum efficiency, as indicated by a vacuum gauge, when on regular work. The condensing or injection water enters at the top, and passing through the water nozzle has its velocity increased on entering the condensing tube, which is in the exhaust steam space, by the condensation in it of the steam. This velocity is further increased by the jets of steam entering through the inclined side holes. The condensed steam and the water rush downward to the outlet from which they can be carried to a cooling pond or elsewhere. At the top is a small nozzle by which a jet of live steam can be introduced at starting, so as to lift the injection water and prime the apparatus. M.2523.

APPLIANCES CONNECTED WITH WATER SUPPLY.

The reference here is not to those important works of the ancient and modern world for supplying districts and cities with water for irrigation and domestic purposes, but rather to those appliances connected with the control and distribution of the water supply itself. In early times such distribution was hardly attempted at all; water was allowed to flow continuously through a conduit, stand-pipe or fountain whence supplies were carried away for use, in the way still to be seen in some Continental cities.

Pipes.—The Romans in their domestic arrangements used pipes of stone and earthenware, and for higher pressures made them of sheet lead folded over and united along the top by a soldered joint. In London a limited supply from old London Bridge Water Works (*see* No. 612) and from the New River head was distributed in leaden pipes, but both stone pipes, jointed with stone sleeves, and wooden pipes (*see* Nos. 702–4) were what were in general use down to the 18th century. Indeed, cast-iron mains were only introduced in London about 1800, and it was 20 years before they had superseded wooden pipes. Wrought iron and steel pipes have been used to a limited extent within recent years, while reinforced concrete pipes, being practically indestructible, are coming into favour rapidly. In the Western States of North America wood, in the shape of built-up stave pipes with external iron hoops, is superseding metal, and mains upwards of 52 in. diam. for heads of 200 ft. have been so constructed. Wood-lined steel pipe is in use for conveying sea water or corrosive liquids. For pipes of small diameter, lead has continued to be the material employed. About the 16th century, a new method of making leaden pipe, by casting it in a mould with an iron core, was introduced, but this did not admit of very long lengths being made. In 1790, John Wilkinson patented the method of drawing cast lead pipe over its core or mandrel; pipe of any length was made by squirting lead under hydraulic pressure, as proposed by Bramah in 1797 but not carried into practice till a quarter of a century later by Hague.

Cocks and Taps.—The early stop-cocks were of the simple open plug type. Sometimes they were in wood (*see* No. 703), but the defects of this material for the purpose are obvious, and metal soon became universal. Butterfly valves were used also, but the sluice valve, now universal for mains, was introduced in the middle of the 18th century. The water tap for small pipes is generally of a screw-down form, but its defects have led to many improved forms being brought out (*see* Nos. 708–11).

Filters.—The natural method of filtration by gravitation is carried out by means of filter beds at the reservoir. The space required and its slowness led at an early date to the construction of pressure filters, *e.g.* Bramah in 1797 patented one for the brewing industry, in which there was a single cell supporting filtering

material through which the liquid was forced by a pump (*cf.* No. 716). To obtain a large filtering area in a small space Messrs. W. Needham and J. Kite in 1852 made use of a number of cells in parallel. The cells were formed of grooved boards covered with cloth alternating with distance frames and stacked vertically, the whole being clamped together by tie bolts. There was a separate pipe joint for each distance frame and the working of the apparatus was slow in consequence. Modern improvements have rendered this so-called "press" very efficient (*see* No. 717). Where the conditions permit it, many filters are arranged to reverse the flow and so automatically cleanse themselves.

700. Model of Norton's tube-well driving apparatus. (Scale 1 : 2.) Lent by Messrs. Le Grand and Sutcliff, 1892.

The tube-well consists of a pointed iron pipe with numerous small holes near the end, which is driven into the ground until a water-bearing stratum is reached, other lengths being screwed on as necessary. A small pump is then attached by which the water is brought to the surface. The method is believed to have been invented by Col. Nelson W. Green, of New York, in 1862; such wells are frequently known as Abyssinian wells, owing to their being first extensively adopted during the British Expedition to Abyssinia of 1868.

Mr. J. L. Norton, in 1867, patented and introduced the arrangement for driving shown in the model, in which a steel clamp is bolted to the tube for the purpose of receiving the blow of an annular driving monkey. By means of ropes passing over sheaves at the top of a tripod, the monkey is raised, and, sliding on the tube as a guide, is allowed to fall upon the clamp, and thus drive the tube into the ground. M.2435.

701. Model of tube-well driving apparatus. (Scale 1 : 2.) Lent by Messrs. Le Grand and Sutcliff, 1892.

In this arrangement the driving monkey is guided by the inside of the well tube. A steel cap is screwed on the top of the tube, and receives the blow of the monkey, which has a guide rod entering the tube. For small tubes, as in the model shown, the monkey is lifted by the upper portion of the guide rod, no guide or tripod being required, but heavy monkeys for driving large tubes are raised by a rope or chain gear.

With such apparatus a 2 in. tube well was driven at Norwich to the exceptional depth of 187 ft., the monkey employed weighing 103 lb. M.2436.

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702. Early water pipes. Presented by the New River Co., 1902.

These are specimens of the wooden pipes used in London before the adoption of iron water mains. The wood generally employed was elm, and owing to the inability of such timber to resist considerable pressure the diameter of the internal hole was usually limited to 6 in. or 7 in., though in favourable situations bores of 10 in. or 12 in. were sometimes adopted. The usual practice where extra carrying capacity was required was to increase the number of 6 in. pipes, so much so that in one street in 1810 there were nine of these lines of pipe laid side by side. The leakage was serious, being estimated at about 25 per cent. of the total quantity of water admitted. Wooden pipes had been in use for many years when an improvement was made in the methods of connecting them. It consisted of introducing an

iron band driven into the timber around the socket end, to prevent the bursting of this part through the expansion of the wood, upon which action the tightness of the joint depended.

The boring of the holes was performed either by augers or by a method patented in 1796, in which a hollow iron tube with a circular cutter at the end removed the centre of the trunk in one piece, which could be used for a smaller pipe or for other purposes, the tool being an anticipation of the trepanning tool sometimes used in boring guns. M.3249.

703. Wooden water pipe and valve. Lent by T. E. Gibbons, Esq., 1910.

This pipe, with other objects, was dug up in Forton Road, Gosport, and is believed to have formed part of a plant laid down by a certain Thomas Lewis of London, who obtained an Act in 1698 for supplying Forton with water. It is of elm, 5 in. diam., and of hooped-construction like the adjoining one (*see* No. 702).

A wooden stop valve of the open plug type, from the same place, is shown. The plug is not tapered; originally, when swollen with the water it must have fitted the wooden casing. M.3723–4.

704. Wooden pipe connections. Lent by T. E. Gibbons, Esq., 1910.

These fittings for connecting wooden water mains to the leaden service pipes are of the same origin and date as the adjoining pipe (*see* No. 703). The leaden pipe was soldered to a tapered gunmetal spigot which was driven into a hole bored in the water main, the method being obviously borrowed from that adopted with a cask. M.3726.

705. Amalgaline metal jointing. Presented or lent by the Metal Jointing Co., Ltd., 1913.

This improved process of jointing lead pipes, etc., was patented by Messrs. T. Harden and S. Smith in 1905–11. Joints made on this system are superior to the old plumber's wiped joint, in that they are neater, more easily and quickly made, and are stronger than the pipe itself.

The method consists in cleaning the two lead surfaces to be joined, placing between them a piece of "amalgaline," which is a strip of tin foil ·002 in. thick, coated with a special flux composed of stearin and vaseline, pressing the two together, and heating by means of a blow-lamp until the tin melts, which it does at a lower temperature than the melting point of lead. The tin amalgamates with the lead and forms a joint which is indistinguishable from the solid metal.

Water pipes are joined with the conical spigot and socket joints which give a clean bore and do not increase the external diameter. The coned ends are formed by the special cutters shown, which consist of a mandrel fitting the pipe and having a squared end for turning with a brace, while a flat cutting blade is attached to it by screws. A prepared and finished joint are shown. Branches are made with cast lead tee or elbow sockets which are coned inside to fit the pipe ends, no machining being necessary; reducing sockets are fitted in the same way. Brass fittings, after tinning, are securely joined to the pipes with "amalgaline," as shown by the examples, as also are cast lead tacks for fastening the pipes to walls, etc.

Sanitary pipe joints are made by cupping or expanding the end of one pipe and fitting the end of the other piece inside it, with "amalgaline" between the surfaces to be joined. The pipe is cupped by means of the aluminium mould and wooden mandrel shown. Clean branches are easily made on such pipes. Inv. 1913–97 to 104.

Cocks and Taps.

706. Stop cock. Lent by T. E. Gibbons, Esq., 1910.

This is a stop cock, for a wooden water main 4 in. diam. similar to the adjoining (*see* No. 703), but is believed to be of later date; it was dug up in High Street, Gosport. It is of the open plug type with two spigot ends. The body is of cast iron but the seating on which the plug works is of gunmetal to prevent sticking. The plug is kept tight by a gunmetal-bushed crosshead and two hooked bolts. M.3725.

707. Water taps. Presented by Mons. E. Bourdon, 1876.

These represent two forms of valve, patented by Mons. Bourdon in 1867, in which the passage is controlled by a rolling curtain, or flap, of leather. The valve is constructed as a cylindrical casing, which may have a glass front, and the water enters directly into the casing by one orifice and leaves it by a lower orifice provided internally with a circular seating of large radius pierced with a number of small outlet orifices. To one extremity of the seating the end of a leather flap is secured, while the other end of the flap is attached to an arm which may be turned by an external handle, by which means the number of holes covered by the flap can be varied, and thus the discharge be controlled. M.1841.

708. Water tap. Lent by the Palatine Engineering Co., 1891.

In this tap patented by Lord Kelvin in 1889 and 1891, the valve is screwed down on its flat seating, but when in contact a gradually increasing pressure is applied by means of the internal spring, so that the valve rotates and cleans its seat before quite closing. There is no packing to prevent upward overflow while open, but any water escaping past the screw is drawn off by a tube inside the spout, the flow of water inducing the current. M.2410.

709. Water tap. Presented by R. E. Prosser, Esq., 1901.

This arrangement of bib tap was patented in 1898 by Mr. G. O. H. Klopp. In it the flow of water is controlled by a hollow ball of vulcanite or metal which is forced upward, by the water pressure, against a ring seating of rubber, while a screwed vertical spindle enables the operator to push the ball downward from its seat to any desired extent. No gland is used, as the leakage from the spindle while the tap is open is conducted into the outlet. The rubber washer can be replaced under pressure, as, while this is being done, the ball beds on a metal seating. M.3192.

710. Bib taps. Presented by Garratt's Patent Screwdown Valve Co., 1910.

This shows a design of tap, patented in 1908 by Mr. J. T. Garratt, to obviate the destructive grinding action on the washer which takes place in the usual pattern when the washer is screwed against its seat. The spindle, in place of being screwed, is made like a piston with rubber packing, and has a collar acted on by an external screwed cap. The spindle is prevented from coming out by a screwed ring, and the cap from coming off by a knob screwed on the spindle. The washer is retained by a flanged ring screwed on the end of the spindle. M.3728.

711. Vented plug cock. Presented by F. Ward, Esq., 1906.

This cock is designed to draw liquid from a sealed vessel, such as a cask. The stoppage of flow that occurs when the pressure inside becomes the same

or less than that outside is usually overcome by admitting air by means of a vent peg; in the cock shown this function is automatically performed in the act of turning on the cock itself. Cocks of this kind having an external pipe to the vent were designed as early as 1816; the one shown was patented by Mr. Ward in 1904. A vent pipe reaching from the nose of the plug to a chamber within it communicates with a similar pipe extending to the spigot inside the cask when the plug is turned full open. When the liquid in the receptacle to be filled reaches the level of the nose of the plug no more air can enter and flow ceases. A vent in the casing admits air to the plug when turned off so as to empty it. M.3455.

712. Valves for water-closets. Contributed by P. J. Davies, Esq., 1873.

These valves, patented in 1872 by Mr. P. J. Davies, are for regulating the flow of water in water-closets, and preventing waste by releasing the valve by means of a cataract, and allowing it to close when a sufficient quantity of water has passed. The following description of one form will explain the principle: a closed metal cylinder, in which works a piston, is fixed on the top of a leather-seated valve; the pull of the handle is communicated by a wire to the piston rod, and the water contained in the cylinder can only leak slowly past the piston; the cylinder and valve are lifted with the piston, but gradually drop and shut off the water, even though the handle may be held up. M.1287.

713. Model of water-closet mechanism. Presented by T. Penn, Esq., 1873.

This is a mechanism, patented in 1870 and 1872 by Mr. T. Penn, for application to water-closets on the old pan system; its object is to release the ordinary valve lever so as to prevent waste of water. A vertical sliding bar, with its attachment, is lifted by the pull of the handle; a quadrant lever lifts the ordinary valve lever, which opens the valve. The quadrant lever is held in its normal position by a balance-weight and by a cataract; it will therefore yield slowly and release the valve lever if the handle should be held up for any length of time. M.1305.

714. Leakage detector. Presented by H. H. Sporton, Esq., 1901.

This is an instrument for rendering audible the slight sound made by water flowing in a pipe, so that if the noise continues, after certain valves are closed, the existence of a leak is indicated. It was originally invented in 1881 by Dr. J. Graham Bell, and by its use in Cincinnati in the following year it was believed that the waste of water was halved. It consists of a circular box of hard wood, provided with a central orifice resembling that of a telephone, and containing a thin disc of metal, free at its circumference, but secured at its centre to a wooden rod 3·5 ft. long, extending from the back of the box. When the ear is placed at the orifice and the further end of the rod is in contact with a water pipe, the sound from the pipe is transmitted by the rod to the disc, which causes the whole of the air in the box to vibrate, so that the sound is heard considerably magnified by an ear applied at the orifice. Mr. Sporton found that by dishing the disc and cutting it to a polygonal outline, as shown, the action was intensified. M.3167.

715. Sectional model of rain-water separator (working). (Scale 1 : 4.) Lent by C. G. Roberts, Esq., 1891.

This shows an automatic apparatus patented in 1883–5 by Mr. Roberts, for separating the first portion of the rain water, coming from a roof during a shower, from that falling afterwards. It is stated that in the country one gallon per 100 sq. ft. of collecting area is necessary to cleanse the roof and gutters, and double this quantity in cities. The apparatus is adjusted so that

the desired amount of cleansing water shall be rejected, or run into a tank for impure water, the rain falling afterwards being delivered into the clean water storage tank.

The separator consists of a sheet metal casing, provided with a pipe above, through which all the water from the roof enters. In the middle of the case is a drum capable of swinging on a horizontal axis, and provided below with two discharge outlets, the right-hand outlet being the main one. Below the drum is a chamber divided by a partition and provided with two outlets, the one to the right being connected with the clear storage tank and the other with the waste. The drum has a chamber which, when filled with water, causes it to rotate, so as to place the main outlet over the clean water discharge pipe. This chamber is situated under a small orifice in the upper casing, so that a small proportion of the water entering the machine shall pass into the chamber, and so in time by its weight throw over the drum. It is then held in position by this small stream filling a tank at the top left-hand portion of the drum, from which it is conducted by a pipe at the back to the main outlet, while at the same time the contents of the drum chamber are delivered into the waste discharge by a small automatic siphon. When the rain ceases this small tank soon empties, so letting the drum swing back into the position for dealing with the impure water at the commencement of the next shower. Doors are provided for removing the various strainers, and the central drum can be withdrawn for cleaning. A horizontal arrangement of the apparatus is also made, for fitting in situations where the height is restricted. M.2416.

716. Feed water filter. Made by Messrs. Maudslay, Sons & Field. Received 1909.

This is a filter for removing grease from condenser water before feeding it back into the boiler. It has a cylindrical chamber with a removable top cover and water connections at the top and bottom. Within this is a "cartridge" consisting of a number of horizontal circular grids, between which are placed sheets of wire gauze and turkish towelling or flannel. The cartridge is held down on a flange by set screws passing through stuffing boxes in the cover, and the water, entering at the bottom, passes up through the grids and leaves any grease in the towelling. The filter is arranged with a by-pass in the piping so that it may be cut out for the purpose of substituting a clean cartridge for the dirty one. The filter is designed for a pressure of about 150 lb. per sq. in. M.3701.

717. Model of filter press. Lent by Messrs. S. H. Johnson & Co., Ltd., 1906.

This illustrates the modern form of press in which the cells rest upon and slide along two side bearers; passages for the inflow of the liquid are contrived within the margins of the plates and all joints are made simultaneously by tightening a single screw; the construction is entirely in metal. These improvements are mainly due to M. V. Danek, in France, and to Mr. S. H. Johnson, in this country, between 1862 and 1876. The improvements since effected have been in detail to adapt the press to such different substances as oil, sugar, sewage sludge, gold ore slimes, etc.

The model has, however, only a few of the cells of which an actual press would be made up. The cells are of the flush plate type with the pyramidal drainage surface patented in 1890 by Mr. Johnson, *i.e.*, they are covered with studs or bosses which, while equally efficient as fine ribs in giving support to the filter cloth or paper, give a greater area for the filtrate. Holes are cut in the paper or cloth to match the passages through the margin of the frames. The depth of the cell, and consequently the thickness of the cake produced, is determined by the distance frame. A hand pump, with an air vessel and pressure gauge, is provided for forcing in the liquid. After the cells are filled, the precipitate may be washed free from the filtrate by forcing liquid through the same or a similar passage. M.3451.

FIRE PROTECTION.

Fire Engines.—Provision for extinguishing a conflagration was made by the ancients, who provided and used what are now known as fire buckets, while the Romans had leather water bags with pipes attached from which jets were projected by pressing the bags. Hero of Alexandria, about A.D. 50, described "the siphon used in conflagrations"; it was a double cylinder manual fire engine delivering an intermittent jet through a branch pipe carried by a swivel joint; little further advance was made during the following 1,500 years. In 1670 Van der Heide introduced the use of leather hose for the suction and delivery pipes; the air vessel to give a continuous jet was added at about the same time. In England till early in the 18th century the only form of engine was the fire squirt which held three or four quarts of water; about 1720, however, Richard Newsham introduced the typical parish fire engine, and the first engine in America was also of his make. The steam fire engine was invented by Braithwaite in 1829 and first used on a fire at the Argyle Rooms in London in the following year, but the general adoption of such engines only commenced in the fifties, about which period also the floating engines on the Thames were introduced.

Sprinklers.—These arrangements, for delivering water sprays at fixed points in buildings, aim at the extinction of a fire in its early stages. The jets are all connected with the water supply, or with an elevated tank, and can be turned on in groups by hand, or else are started automatically, when the temperature in any portion of the protected area rises abnormally. Some arrangements depend on a thread being burnt through, but the usual plan relies upon the release of a valve held in place by levers connected by a solder fusing below the boiling point of water.

Alarms.—Many appliances have been introduced which should give warning upon the outbreak of a fire in any part of a building. One, by Sir W. Congreve, relied on the expansion of alcohol to release a weight-driven train which rang a bell; in another an electric contact was made by a compound bar which curved when heated, but in the latest the expansion of mercury makes a contact in a medium that protects the surfaces. The electric system enables the alarm bell to be at any distance from the fire detectors, and in sprinkler systems there are similar bells which ring when any sprinkler comes into action.

Fire-Escapes.—Numerous devices have been introduced for rescuing persons who may be in a burning building. Some of the earliest consisted of a slung seat attached to a rope, by which a person lowered himself from a window, just as is still provided in wooden houses in Norway. In 1809 telescopic ladders in three lengths were introduced to facilitate escape, while in 1813 a light rope ladder with iron rounds was proposed. In 1816 a long pole, down which a sliding basket could descend, was tried, and in 1820 a large canvas tube extending from the

window to the ground was first used as an escape. About 1835 Mr. Merryweather constructed a series of ladders which would fit end to end till the requisite length was obtained, and about 1840 Mr. Wivell, by combining the portable ladder with the canvas shoot, introduced the now general form of escape.

Fire Engines.

718. Old fire squirt. Presented by the Vestry of St. Dionis, Backchurch, 1877.

This is an old squirt or syringe used about 1750–70 in the City of London for extinguishing fires. It is made of brass, and has two handles cast on, for slinging it during transport and for two men to hold it when in use while a third worked the piston, as indicated in the accompanying woodcut, which illustrates fire extinguishing at three different periods. The bore of the squirt is 2·5 in. diam., and of the nozzle 0·5 in. M.1831.

719. Japanese fire-pump. Presented by H. H. Howell, Esq., 1861.

This form of single-acting hand-pump was in general use in Japan in 1860 for extinguishing fire. The lower end was placed in a bucket of water, and the inclination of the intermittent jet produced on working the handle was adjustable by a swivelling joint in the delivery pipe.

The barrel is formed by boring a hole 1·2 in. diam. through a rectangular post 3ft. long, in which another hole is bored parallel with it up to the junction for the delivery pipe. The lower end of the barrel is fitted with a foot valve in the form of a sheet metal clack, loosely pinned to a wooden seating, and a similar fitting secured in the side passage forms a delivery valve. The piston is formed of cloth tied to a rod resembling a plunger, provided with a cross handle. The jet delivered is 0·2 in. diam. M.1832.

720. Newsham's fire engine. Presented by the Town Council of Dartmouth, 1875. Plate XI., No. 1.

Richard Newsham, of London, in 1721–5, patented "a new invented water engine for the quenching and extinguishing fires," and the example shown is of his make. It has two single-acting pump barrels 4·5 in. diam., 8·5 in. stroke, and a tall air vessel to secure a continuous discharge. The pumps are placed in a tank which forms the frame of the machine, and the water to be pumped was brought in buckets and emptied into the tank, but the suction inlet to the pumps is provided with a two-way cock, by which the pumps can be arranged to draw either from the tank or from a length of suction hose. Leather hose for "conveying water to and from fire and other engines" was patented in 1676, and Newsham used it, connecting his suction hose at the base and the delivery at the top of the casing enclosing the air vessel. The pumps were worked by men at the long cross handles, as in the modern "manuals," but in addition two treadle boards were provided near the centre of the machine, upon which several more men stood and assisted the pumping by throwing their weight on the descending treadle.

These engines were generally adopted, as is shown by the following extract from Newsham's trade circular:—"Richard Newsham, of Cloth Fair, London, Engineer, makes the most useful, substantial, and convenient engines for quenching fires, which carries continual streams with great force. He hath play[d] several of them before His Majesty" (*i.e.*, George I.), "and the nobility at St. James's, with so general an approbation that the largest was at the same time ordered for the use of that Royal Palace." It was remarked

of Newsham by a writer in the *London Magazine* for 1752, that in his engines he gave "a nobler present to his country than if he had added provinces to Great Britain." Desaguliers considered that no part of the engines could be altered for the better, and the general feeling was greatly in favour of them, they being purchased by the various parishes throughout the kingdom, and Newsham received numerous orders for them from all parts of the world.

At the front of the engine, but protected by a door and a sheet of horn, will be found quaint directions for keeping the engine in order. M.1362.

A photograph, presented by the Rev. F. W. Ragg, M.A., of a print dated 1748 showing a Newsham engine at work, is shown in an adjoining case. Inv. 1916–68.

721. Drawing of Braithwaite and Ericsson's fire engine. (Scale 1 : 12.) Received 1869.

This represents the first steam fire engine, which was patented in London by Messrs. John Braithwaite and John Ericsson in 1829–30. It consisted of a boiler and two direct-acting steam pumps mounted on wheels for horse traction, and weighed 2·25 tons complete.

The boiler was similar to that of the "Novelty" locomotive (*see* No. 197), but smaller, and had a vertical cylindrical water-jacketed firebox with a door at the top to feed in the fuel and a closed ashpit below into which air was pumped by a mechanical bellows. From the vertical shell extended a horizontal barrel containing a single flue which traversed its length three times, the waste gases issuing by a funnel near the driver's seat. The pumping apparatus was horizontal with two steam cylinders 7 in. diam., and two pumps 6·5 in. diam.; they made 35 to 45 strokes per min. The slide valves were worked by rocking levers actuated by the crossheads, as were the blowing apparatus and feed pump, but these latter had also hand levers. The feed water was heated by the exhaust steam in passing through a coil. The quantity of water thrown was 30 to 40 tons per hour to a height of 90 ft. through a 1·25 in. diam. nozzle. Although the engine was worked gratuitously at several fires in London with great success, it met with determined opposition. Three or four similar engines were, however, built for Liverpool and abroad, but it was not till 1852 that steam fire engines were permanently adopted in London. M.2772.

722. Drawing of early steam fire engine. (Scale 1 : 12.) Received 1869.

This shows an engine constructed by Mr. P. R. Hodge at New York in 1840, which is stated to have been the first steam fire engine built in America.

It resembled a four-wheeled road locomotive, and was self-propelled; the boiler was of the locomotive type, with Bury's firebox, and there were two outside horizontal cylinders 9·5 in. diam. by 14 in. stroke actuating the wrought-iron driving wheels. When the scene of operations was reached, one end of the engine was raised till the driving wheels were off the ground, when they acted as flywheels. The pumps were placed tandem with the cylinders, and were directly driven by the piston rods produced backward. The delivery took place through from one to four jets, and the quantity of water thrown is stated to have been 290 tons per hour, to a height of 166 ft., when using a 2·15 in. diam. nozzle and drawing from a depth of 12 ft. M.2773.

723. Model of a manual fire engine. (Scale 1 : 4·8.) Made by Thomas Coates, Esq., 1894.

This sectional model shows the construction of a large manual fire engine such as was used by the London Metropolitan Fire Brigade. The

body is of timber and carried on large road wheels, with a fore-locking carriage. It is borne on springs throughout, and provided with a powerful hand brake, and generally arranged for rapid hauling by two horses. The roof of the carriage is hinged so as to give access to the interior, in which the hose and other accessories are conveyed, while the roof also serves as a seat for the firemen, and is furnished with two cross hand-rails for enabling them to retain a firm hold during rapid transit. The tops of the long side boxes, which contain the two lengths of suction hose, also serve as footboards.

The pumping machinery consists of two vertical single-acting pumps packed with cup leathers, and arranged on a base that contains the valve boxes. The valves are simple metal clacks, and are readily accessible by two covers, which are held down by set screws. The suction can be taken in through suction hose, or, when working close to the main, the hydrant delivers directly into the chamber containing the pumps, this arrangement being the same as in Newsham's fire engine of 1725 (*see* No. 720). The delivery passes out through a branched pipe having a union on each side of the engine, and on this pipe is a large copper air vessel to secure a uniform discharge. The pump pistons are steadied by overhead guides, and are driven by links from a horizontal shaft running the length of the machine. The ends of this shaft are fitted with levers, which are connected outside the framing by the two long hand-levers with their extension handles, by which the men do the pumping.

The pumps are 6 in. diam. and 8 in. stroke, and the engine is intended to be worked by 22 men, who will pump 100 gal. of water per min. in a continuous jet to a height of 120 ft. M.2569.

724. Model of a steam fire engine (working). (Scale 1 : 4·8.) Made by Thomas Coates, Esq., 1891. Plate XI., No. 2.

This model and the adjacent sectional drawing show very accurately the construction of a steam fire engine. The machine is carried by large wheels on mail-coach axles, with a fore-locking carriage, and is generally arranged for rapid travelling, two horses being employed. The delivery hose is stored in a central box, which also contains a tank for the boiler feed water. The two lengths of heavy suction hose are carried, one on each side, beneath the firemen's footboard, and a coal-bunker under the fore-carriage holds a supply of fuel conveniently near the furnace door. The box seat is utilised as a tool store, and two short branch pipes with nozzles are carried, one on each side of the box, and two long ones over the hose-box. The pole terminates in a special form of crap, by which a horse that has fallen can be quickly released, and the hind wheels have a powerful lever brake.

The pumping machinery consists of a vertical steam cylinder 7·5 in. diam., 7 in. stroke, and a double-acting bucket and plunger pump with an 8 in. bucket and a 6 in. plunger. The piston is directly connected with the plunger by two piston rods, which permit the horizontal crankshaft to be placed in the centre lines of the engine, a return connecting rod from the interior of the plunger connecting the reciprocating parts with the crankpin. A full stroke is thus secured, and a flywheel introduced which carries the engine over its dead centres. An overhanging eccentric works the slide valve, and also a feed pump attached below in line with the valve-rod. The suction box of the pump is directly below the barrel, and the delivery takes place above, two sluice valves being arranged to direct the water into two lengths of delivery hose. A spring-loaded relief valve permits the return of water from the delivery box into the suction-valve box if the pressure rises above that which is safe for the hose. A large copper air vessel is placed on both the suction and delivery boxes, to prevent any concussion in the pipes, and a pressure gauge in front of the boiler registers the pressure in the hose.

Steam at 100 lb. pressure per sq. in. is supplied by a vertical boiler, internally fired, and having the fire-box crossed by numerous rows of inclined water tubes, the total heating surface obtained being 56 sq. ft. The boiler

shell is in two lengths, bolted together, to render the fire-box accessible for cleaning and repairs. The shell and fire-box expand towards the base, so increasing the grate area up to 4·5 sq. ft., and owing to the exhaust from the cylinder being sent through a blast pipe in the funnel a very sharp draught is obtained. The boiler is provided with two spring-loaded lever safety-valves, an injector, steam whistle, and a jet into the funnel for urging a poor fire, besides the other usual fittings.

The engine indicates 30 h.p., delivers 350 gal. per min., and weighs rather under 1·5 tons. With a 1·125 in. nozzle, the jet reaches a height of 160 ft. Steam is raised to the full pressure of 100 lb. per sq. in. in six minutes from the time of lighting the fire.

This model is in all respects a complete working machine, even to the pressure gauges and injector. The boiler is of copper with 70 cross tubes, and was tested to 300 lb. per sq. in. It burns coal, and has raised steam from cold water in seven minutes. The engine throws a continuous jet 0·187 in. diam. to a height of 65 ft., when running at 360 rev. per min.

M.2404.

725. Model (working) and drawings of a double-cylinder steam fire engine. (Scale 1 : 4·8.) Made by Thomas Coates, Esq., 1892.

This model and the adjacent sectional drawings show the construction of a large steam fire engine with horizontal cylinders such as is used on docks or other large areas of warehouse property. In many respects the details resemble those of the smaller model, but the delivery hose is stored in the front box and two coal bunkers on the footplate hold a supply of fuel.

The pumping machinery consists of two horizontal steam cylinders 7 in. diam. by 7 in. stroke, and two double-acting horizontal piston pumps 5 in. diam. The steam pistons are directly connected with the water pistons by common piston rods. The crankshaft is above the centre line of the cylinders and pumps, and is driven by a return connecting rod from a cross-head, which slides in guides fixed above the pumps and is carried forward and downward to the piston rod. The suction and delivery valve chambers are directly below the pump barrels, and by removing a few bolts the valves are easily accessible. The delivery takes place above, two double sluice valves being arranged to direct the water into from one to four lengths of delivery hose. A large copper air vessel is placed on top of the delivery chamber, and a small one on the suction chamber to give a steady flow in the pipes, and a pressure gauge on the inside of the box above the pumps indicates the pressure in the hose.

Steam at a pressure of 100 lb. per sq. in. is supplied by a vertical boiler, very similar to that in the smaller engine, but having 76 sq. ft. of heating surface and 6 sq. ft. of grate area. The engine indicates 45 h.p., delivers 450 gal. per min., and weighs about 1·75 tons. With a 1·5 in. nozzle the jet reaches a height of 190 ft. Steam is raised to the full working pressure in ten minutes from the time of lighting the fire.

The model is in all respects a working machine, and the boiler, which is of copper, has 80 cross tubes, and has been tested to 300 lb. per sq. in. It burns coal, and has raised steam from cold water in ten minutes. The engine throws a continuous jet 0·2 in. diam. to a height of 75 ft. when running at 280 rev. per min.

M.2451.

Sprinklers.

726. Diagram and details of the Grinnell automatic sprinkler. Lent by Messrs. Dowson, Taylor & Co., 1890.

This device is employed to protect buildings against fire. The fitting, patented in 1881–90 by Mr. F. Grinnell, consists of a ball valve held on its seat by mechanism retained only by soft solder. In the early form shown

the valve was of metal and a releasing lever was employed, but they were found liable to stick. In the later form (*see* No. 727) these defects have been overcome.

Lines of small pipes are carried through the building close to the ceiling and connected with the water main or to an elevated tank so as to secure sufficient water pressure. As soon as a fire occurs the hot air rises to the ceiling, where it soon heats the sprinkler sufficiently to melt the fusible solder and so liberate the valve. The stream of water which then issues impinges on a toothed deflector, by which it is sprayed outwards over a considerable area. Each sprinkler will protect about 100 sq. ft.; they are arranged, therefore, from 8 to 12 ft. apart.

There is an automatic alarm gong which is struck by a rotating hammer, driven by the water directly a sprinkler comes into action. M.2338.

727. Sprinkler head. Lent by Messrs. Mather & Platt, Ltd., 1912.

This is a sprinkler head of Grinnell's latest form, employed as shown in No. 726.

The body is screwed into the water supply fittings and accommodates a flexible diaphragm held in by a screwed ring having an arched extension. A hole, 0·5 in. diam., in the centre of the German silver diaphragm is closed by a hemispherical glass valve. These two materials are found to obviate all difficulties due to corrosion, sticking, etc., to which sprinkler devices are liable. The valve is held on its seat by a strut with a bellcrank interposed between it and its abutment on the arch; the bellcrank is held by a key piece and both are soft-soldered to the strut. Since the latter is slightly out of the line with the arch, axial pressure produces a couple which is only resisted by the solder; when this melts (usually at 155 deg. F. = 68 deg. C.), the pieces collapse and the issuing water, by impinging on a serrated deflector on the arch, is sprayed over a considerable area. M.4045.

Alarms.

728. Fire alarm. Received 1909.

By means of this apparatus, which was patented in 1878 by Mr. E. B. Bright, it is possible at a central station to determine at which of a number of places an alarm has been given. The various places are connected together by a line wire, and at each place there is a definite resistance as well as a switch whereby the line can be connected with earth. At the central station there are a rheostat, a battery, and a relay controlling a separate bell circuit. The various parts are so connected that the line and the rheostat form adjacent arms of a Wheatstone bridge, of which the relay forms the galvanometer arm and two resistance coils attached to the relay form the ratio arms. If the line at any place be connected with earth the alarm bell rings, and continues to do so until the resistance of the rheostat, which can be varied by means of a handle, is made to correspond with that of the line. The position of the handle then indicates the place at which the alarm was given.

The rheostat consists of a series of insulated sectors between which varying resistances are arranged, and each sector bears a number corresponding with one of the outside places. The relay has a coil surrounding a magnetised needle, and mounted on the axis of the latter there are tongues which close the bell circuit when the needle is deflected in either direction.

The relay and the rheostat only are exhibited, and the latter has been partly sectioned. M.3698.

729. Fire alarm. Presented by Pearson's Automatic Fire Indicator Co., 1896.

This is an arrangement, patented by Mr. G. L. Pearson in 1884, by which an electric bell is rung when the temperature at any particular position in a

building rises above a certain fixed degree; it is also adapted for indicating dangerous conditions arising in chemical manufactures.

The apparatus consists of a number of thermometers distributed over the rooms that are to be protected, connected in parallel by two insulated wires terminating in a dry battery, a call-bell, and an indicator board. Each thermometer has fused into its tube, at a height corresponding with the danger temperature, two platinum wires, so that when the mercury rises sufficiently it places them in electrical contact; these platinum wires are connected with the bell circuit. When the building is large there are several circuits, each having a separate signal on the indicator board, which then shows in which circuit the contact that is ringing the bell has been made. To prevent the destruction of the platinum and mercury contacts by sparking, the upper portion of the thermometer contains a purified liquid hydrocarbon. To ensure that the main circuits and bell are in working order, independent test wires are laid by which each circuit can be tried by pressing a button in the indicator room. M.2943.

Fire-Escapes.

730. Models of early fire-escapes. (Scale 1 : 6.) Received 1899. Drawings from Woodcroft Bequest, 1903.

Although the formation of a society for the protection of life from fire had been advocated by Mr. J. Hudson in 1828, the first effective organisation for the purpose was that founded in 1836 as "The Fire Association of the South-Western District of St. Pancras." In the same year also the "Royal Society for the Protection of Life from Fire" was established for the purpose of providing fire-escapes throughout the whole of London.

Previously, fire-ladders were kept at certain spots by the various parishes, but the inadequate nature of the appliances and the lack of organisation caused the loss of life by fire to be so serious that some improvements were generally demanded. Various portable arrangements for facilitating escape from burning buildings were designed by different inventors; but to Mr. Abraham Wivell, an artist, appears to be due the introduction of the most important improvements in fire-escapes, and these are embodied in the models shown, which were used by him about 1836, when lecturing upon this subject. He also advocated the provision of fire-escape stations throughout the London district, as indicated by him on the accompanying map; with the result that by 1865 eighty-five of these stations had been established.

One of the three models shown bears the Royal Society's name, and represents a very complete arrangement. It consists of a main ladder mounted upon a spring carriage, with two large wheels, and provided with a lower framework by which it can be handled and elevated. The ladder is of such a length as to reach to the windows of the second floor of a dwelling-house, while hinged to the top of it is a swinging ladder which, by means of ropes from levers projecting from it, can be swung upward as an extension that will reach to the third floor. There are also two short ladders, one of which can be attached to the folding ladder when a greater height is required. Beneath the main ladder is a canvas trough, or shoot, down which a person can be passed, and at the upper end of this ladder are rollers to facilitate its elevation against a wall.

In a second model, the upper portion of the ladder slides in roller guides, and is elevated by ropes passing over the terminal pulleys. At the head there is a pulley block for use when lowering persons by a rope.

The third model consists simply of two ladders, hinged together and capable of being locked in the extended position by rectangular collars when the full length is required.

Several original drawings by Mr. Wivell show the ladders as actually used. M.3057

LAND TRANSPORT.—I.

Common Roads and Road Vehicles.

Common Roads.—The Romans appear to have been the first to construct roads systematically, and their practice was to make them as direct as possible with little regard to gradient. As late as the 16th century the Roman roads were the only ones in England, and even these had been so neglected that travelling was possible only on foot or on horseback. Stage wagons and coaches gradually led to an improvement, while between 1775 and 1800 Macadam and Telford effected changes that brought the leading roads into a state which assisted in a great development of the stage coach service. The introduction of railways checked further progress in this direction for many years, so that but few important works were undertaken, but more recently the high roads have again received attention and their foundation and general surface has been greatly improved, largely owing to the extensive use of steam road rollers which were first adopted in 1863.

The wear of roads, under horse-drawn traffic, is approximately accounted for as follows: Atmospheric influences, 20 per cent.; wheels, 30 per cent.; horses' hoofs, 50 per cent.; so that the great cost of maintenance can still be reduced if, by levelling and keeping the surface in good repair, the number of animals employed is diminished. The greatly increased number of light high speed, and heavy moderate speed, mechanically propelled vehicles has had very destructive effects on the roads, so that recently much attention has been given, both to waterproofing the surface, so as to reduce the dust nuisance, and also to reinforcing the road crust, so as to resist the destructive deformation caused by these vehicles.

Carts and Carriages.—The earliest form of wheel, after rollers, was solid without spokes, as is still general in the East; spokes and tires were subsequently added, but the use of springs was discovered much later, probably because the reduction they cause in the resistance is not noticeable unless the roads are tolerably good.

Stage wagons which had been introduced into England prior to 1600, had by 1640 attained a speed of four miles an hour, while by 1750 stage coaches were regularly at work, and these continued to improve till 1836, when the average speed was about eight miles an hour and the maximum eleven; the introduction of railways then caused their rapid decline.

On a good level road the resistance of a wagon with iron-tired wheels and without springs is about 44 lb. per ton, while with springs it is but 35 lb. The resistance of an omnibus was found to be 100 lb. per ton, on newly-laid macadam; 45 lb. on good macadam; and 30 lb. on asphalt or granite at a speed of

3·5 miles per hour; solid rubber tires reduce the resistance very little, but pneumatic tires reduce it by about 25 per cent. On a tramway the resistance is about 25 lb. per ton, and on a railway only 8 lb. at this speed.

Cycles.—Although cycling has not had any very extensive practical application, beyond its use as a means of promoting healthy exercise, it has become an important means of transport for short distances.

The earliest form of cycle was the "hobby" or "dandy-horse," introduced about 1815, which was essentially a bicycle without pedals, the rider propelling the machine by striking backwards upon the ground with his right and left foot alternately, while maintaining the balance by steering. The arrangement, however, did not possess sufficient merit to overcome the ridicule that it excited and had almost become obsolete when, about 1840, it was developed into a rear-driven treadle bicycle, by Kirkpatrick Macmillan, a blacksmith of Courthill, in Dumfriesshire. Although many of these bicycles were made, the machine did not become popular, and for some years was neglected, while tricycles or "velocipedes," some of which had a front driving wheel, were introduced. In 1866 Pierre Lallement, a Frenchman, fitted cranks to the front wheel of a bicycle and this machine, when introduced into England in the following year, became the first popular bicycle; it was known as the "boneshaker," and had a front wheel 3 or 4 ft. in diam., and a back one 2·5 to 3 ft. In 1868 Mr. E. A. Cowper adopted the suspension wheel which had, however, been patented in 1802, and in 1870 Mr. J. K. Starley patented an arrangement of tangented spokes, while at about the same time rubber tires were added. To increase the speed attainable the diameter of the front or driving wheel was gradually enlarged to more than 60 in., and in this way was evolved the high and rather dangerous machine known as the "ordinary," which was for many years the accepted form of bicycle. Several arrangements of link work and gearing were introduced, however, with the object of reducing the liability of the machine to capsize on meeting any exceptional obstruction; but in 1879 Mr. H. J. Lawson constructed a rear-driven geared bicycle, which in 1885 was brought to the present "safety" form by Mr. Starley, who commercially introduced it. A great step in the evolution of high-speed road vehicles was made in 1888 by Mr. J. B. Dunlop when he re-introduced the pneumatic tire.

The almost universal employment of the free-wheel clutch and the increasing use of variable speed gears are more recent developments.

Almost every improvement in bicycles has been equally suitable for tricycles, the main difference being the necessity in the latter for a differential gear for turning curves; this difficulty appears to have been permanently solved at the outset, however, by Richard Roberts who in 1832 patented the application of the three-bevel or spur wheel "Jack-in-the-box" for this purpose.

731. Sedan chair. Lent by H.M. War Office, 1867.

The Sedan chair, so called because it was first made at Sedan in France, is said to have been introduced into England as early as 1581, but its most popular period was the 18th century, when it was largely used in the same way as is the modern cab. The example shown dates from the latter part of that century.

The chair consists of an enclosed seat provided with a glazed door at the front, a window at each side, and a hinged roof to facilitate entry and exit. It was carried by two men by means of horizontal lancewood poles that passed through sockets fixed at each side. The frame of the chair is covered outside with leather, and ornamented with rows of nail heads, while the inside is upholstered in cloth. A loose cushion is provided for the seat. Sedan chairs for private use were frequently of a highly ornamental character.

The chair shown measures 2 ft. wide, 2·5 ft. deep, and 5·25 ft. high; the poles are 11 ft. long. M.4217.

732. Model of Siamese sledge. (Scale 1 : 8.) Lent by L. H. Pritchard, Esq., 1908.

This represents the form of vehicle used in Siam, for conveying the produce from the rice fields to the homesteads. It is a sledge consisting of a square platform mounted, a short distance above the ground, on bent bamboo runners which serve as shafts to which a water-buffalo is yoked. M.3548.

733. Antarctic sledge. Lent by the British Antarctic (Terra Nova) Expedition, 1914.

This is one of the sledges used by Sir E. H. Shackleton on his Antarctic expedition of 1907–1909. It is of the type adopted by Capt. R. F. Scott for his earlier expedition, and was made at Christiania after the pattern designed by Dr. F. Nansen.

The sledge has a pair of wide hickory runners which are bent upwards at each end and have a strengthening rib along the back. The ribs are mortised to receive the tenons of short ash posts which are tied to them by raw hide lashings passed through holes. The tops of the posts are tenoned into ash crossbars to which they are lashed, while these joints are stiffened by iron angle bars lashed to the posts and crossbars with steel wire. Above the ends of the crossbars long thin ash bearers are secured by hemp lashings, and the ends of these are bent downwards and similarly lashed to the ends of the runners. At the front end the runners are connected together by a bent piece of ash lashed to them. The only stiff joints in the sledge are those connecting the crossbars and posts; the others are flexible so that the sledge is free to accommodate itself to the surface over which it is moving. The hemp lashings are protected against chafing by raw hide covers. An alpine rope trace, for hauling the sledge, is secured to the first two pairs of posts. The straps for securing the load are also shown.

The sledge is 12 ft. long, 22 in. wide and 7·75 in. deep, its weight being 48 lb. The runners are 3·75 in. wide at the front but only 2·25 in. wide at the back. The normal load for such a sledge is about 600 lb. which could be hauled by three men. Inv. 1914–133.

734. Sledging man-harness. Received 1914.

This shows the type of man-harness used by Capt. R. F. Scott and Sir E. H. Shackleton in their Antarctic expeditions. With it, hauling is done from the waist and not from the shoulder as in previous practice.

The harness consists of a wide canvas waist belt supported by canvas braces passing over the shoulders. The ends of the belt are provided with

eyelets through which the end of the hauling rope is passed and then spliced into a loop. The other end of the rope is looped for attachment to the sledge trace. Inv. 1914–136.

735. Model of Chinese wheelbarrow. (Scale 1 : 6.) Presented by R. Swinhoe, Esq., 1870.

This form of wheelbarrow, which has been in use from remote times in China, has advantages over the European arrangement in that it accommodates a much larger wheel, thereby reducing the rolling resistance, and in having the wheel almost directly under the load, thus throwing but little weight on the user's arms; it requires the load to be in two portions of nearly equal weight and is not capable of directly carrying or discharging loose material.

The shafts are framed together into an open platform, upon which is built a central structure covering the wheel and also affording facilities for securing the objects to be carried. The joints are made by mortising, but some of the parts are stayed by cords which are tightened by twisting them with a stick.

In the print below is shown the method of using these barrows for material, but when employed for the conveyance of passengers one person sits on each side, so that they are back-to-back. M.1712.

736. Models of Burmese carts. (Scales 1 : 6 and 1 : 12.) Contributed by J. Coryton, Esq., 1873.

This form of two-wheeled bullock cart is common in Burma and Bengal, and is a survival of a primitive type of wheeled vehicle. It has solid disc wheels, which are, however, provided with long wooden bushes running on a fixed axle-tree; the oxen are tied to a yoke bearing against their humps and lashed to an ornamental pole, which is forked at the inner end for attachment to the axle and to the body framing. The smaller model is that of a pleasure vehicle, and has modern spoked wheels and an iron axle. M.1315.

737. Model of Siamese cart. (Scale 1 : 12.) Lent by L. H. Pritchard, Esq., 1908.

This represents the ordinary travelling cart used in Siam. It is constructed entirely of wood and has a long narrow body, with sides formed of vertical bars inclining outward at the top, surmounted by a semicircular roof of matting. It has two spoked wheels with very long hubs, each running loose on a separate axle; these axles are supported at both ends, the inner ends by a cross beam under the floor, and the outer ends by side bars which are mortised into long cross beams attached to the body before and behind the wheels. The sides of the cart are supported from these cross beams by inclined bars and stayed by twisted cords. The two main beams of the framing are brought together at the front and prolonged to form the pole to which are yoked a pair of water-buffaloes. The rear ends of the outside frame bars are curved upward and serve to extricate the cart should it sink into soft ground. M.3547.

738. Prints showing types of horse omnibuses, 1912. Presented by the London General Omnibus Co., Ltd., 1912.

These prints show stages in the development of the horse omnibus. A public vehicle running to a schedule was established in Paris in 1662, but was soon abandoned; similar vehicles were, however, successfully re-established in Paris in 1819 by Mons. Lafitte; the name "omnibus" was applied to them by Mons. Baudry, of Nantes, in 1827. Omnibuses were introduced into England by Mr. G. Shillibeer, a coach builder, who commenced to run with two of these omnibuses between Paddington and the Bank on July 4th, 1829. Shillibeer's vehicle, shown in the first print, seated 22 passengers inside and

was drawn by three horses, the fare being one shilling for the whole distance or sixpence half way.

This vehicle was found too large and was followed by a smaller type drawn by two horses and seating 12 passengers inside, and two outside beside the driver. By 1848 a low longitudinal seat for five persons, on the off side, approached by bracket steps, had been placed on the roof; the seats beside the driver were extended so as to seat four persons.

The London General Omnibus Company, formed in 1855 in Paris, but not registered in London till 1858, started business in January, 1856, with some 300 existing London omnibuses which had been purchased from different owners. In order to obtain an improved vehicle, a competition was held in 1856, with the result that omnibuses of the type shown in the second print were built. These had the roof raised at the centre, giving increased head-room inside and forming a double longitudinal roof seat holding 10 persons. There were windows at the sides, the front and back were solid, the corners were well rounded, and the rear entrance was closed by a door, while large steps were provided for entering and for the conductor to stand upon. Most of these improvements, however, had been patented by Mr. W. B. Adams (*see* No. 744).

The London Road Car Company was formed in 1880 and amalgamated with the London General Company in 1908. The third print shows the type of vehicle used by them in 1881. These had very small front wheels and a front entrance platform with steps leading from either side to the roof seat; they were found unsatisfactory and were soon replaced by a greatly improved type, which was subsequently adopted by other companies. This type had an enlarged square body, with windows all round and no door; but the chief improvement lay in the use of transverse seats on the roof, rendered accessible to both sexes by the addition of a large rear platform with a staircase. This final form, which seated 12 passengers inside and 14 outside, is shown in the fourth print, and was used up to October 1911, when it was finally superseded by the motor-omnibus (*see* No. 179). M.4038.

739. Royal mail coach, 1830. Received 1912.

Public wagons for carrying goods and passengers, performing a definite distance or "stage" were in use towards the end of the 16th century while stage coaches appeared about the middle of the 17th century. The mails, however, were carried by post-boys on horseback, but their speed, averaging only about 3·5 miles an hour, and the frequent robberies that took place, led to the suggestion, by Mr. John Palmer, that the mails should be carried by coaches provided with an armed guard, and adapted to run at a good speed. This plan he carried out successfully in 1784, with coaches similar to the existing stage coaches, but which carried only six persons and ran at an average speed of six miles an hour. About the year 1800 the coaches had attained their final form, carrying four passengers inside and four outside, and they travelled at a speed of about eight miles an hour. In 1835 there were 700 such coaches on the roads of Great Britain and Ireland. Their general use ceased about 1838, owing to the advent of railways. Similar coaches, with a larger passenger capacity, have continued in use where there are no railways, or as private vehicles. The coach shown was built about 1830 and, when its mail service was finished, it ran as a private coach until 1894.

The coach body is strongly framed in one with the driving box and the hind boot, the latter being made of the full width so as to hold a large number of mail bags; it accommodates four persons inside, four on a transverse seat on the roof at the front, and one beside the driver, while there is a single seat for the guard mounted on the top of the boot. The body is supported from the underframe by eight semi-elliptical springs, four to each axle, each set having two transverse inverted springs bolted to the underside of the body, with their ends shackled to the ends of two longitudinal springs which are bolted to the axle-trees. The underframe with its swivelling fore-carriage is of wood strengthened with iron, and consists of two cross-beams connected by a

curved perch bar, strutted laterally by two side members from the rear beam. The longitudinal springs are bolted to the ends of the cross-beams and the iron portion of the rear axle is clamped to the upper side of the rear one. The fore-carriage, which is pivoted to the centre of the front beam, is composed of a wooden axle-tree with the iron axle clamped underneath, and four longitudinal bars that pass through the axle-tree and carry the trace bar and pole attachment at their front ends, and at their rear ends a curved iron plate which bears against the perch. The boot orginally opened at the top for the easy reception of the mail bags, but now opens at the back; a blunderbuss case is provided in front of the guard's seat. The inside of the coach is upholstered all over and it has lights in the upper part of the doors only. The rear wheels are 48 in. diam., the front wheels are 38 in. diam., and the wheel base is 6·5 ft. The coach was drawn by four horses. M.4058.

740. Model of royal mail coach. (Scale 1 : 3.) Lent by Maj. G. H. A. White, R.H.A., 1914.

This represents the last mail coach that ran between London and Holyhead. The model was made in 1842 by the son of the coachman who drove it. It resembles closely the actual coach (*see* No. 739).

The underframe consists of a perch connecting two wooden cross-beams each with four semi-elliptical springs supporting the body. The rear cross-beam acts as the hind axle-tree and the front cross-beam is supported on the fore-carriage so that the latter can swivel on a perch bolt. The fore-carriage comprises the axle-tree, with longitudinal beams and stays carrying the trace bar and pole attachments in front, and behind a curved iron plate bearing against the perch. The boot opens at the guard's feet for the reception of the letter bags. The case in front of the guard's seat is for a blunderbuss and there is a horn beside it. Spare trace bars, etc. are carried, the whole coach being represented in running order. The rear wheels are 49·5 in. diam., the front wheels, 37·5 in. diam., and the wheel base, 6·4 ft. Inv. 1914–38.

741. Original brougham. Lent by the Worshipful Company of Coachmakers and Coach Harness Makers, 1895.

This carriage is stated to have been built in 1838, under the personal direction of Lord Chancellor Brougham, by Messrs. Robinson & Cook, of Mount Street. As the vehicle then in general use by the wealthy was the ponderous coach, the appearance of this small, closed, one-horsed carriage created a great sensation, and led to a complete change in carriage design both here and on the Continent.

It has been several times repaired, and the steps are of later construction, while as originally finished the colour was light olive green, picked out with black, and edged with yellow, but the lining was of blue cloth and ribbed silk, probably as at present. The surfaces of the body appear now very flat and unrelieved, but the more noticeable peculiarities are the projecting case and the guard board behind. Such a case was at the time provided on all coaches, and was originally intended for holding swords, which were thus accessible from inside. The guard board, which is 1 in. thick, and carried by detachable brackets, was known as an "opera board," and was placed in position when the carriage was likely to be used in crowded traffic; the then defective police control and other causes rendered "poling" by the following carriage a serious and imminent danger. M.2732.

742. Photographs of Tilbury gig. Prepared in the Museum, 1914.

These show the form of gig, or light two-wheeled one-horse carriage, introduced early in the 19th century by a coachmaker named Tilbury. This example is believed to date from about 1830.

The shafts are carried to the back and, with two cross members, form the main frame which is supported on a pair of semi-elliptical springs bolted to the axle. The body is independently sprung from the frame by four cantilever springs, two at the front and two at the back, the ends of the latter being hung from the ends of a straight transverse spring mounted on a central pillar rising from the frame. Inv. 1914–207.

743. Model of tipping wagon. (Scale 1 : 8.) Presented by the Commissioners of Patents, 1857.

This represents a four-wheeled wagon brought out by Mr. R. Stratton in 1841, and is so arranged as to discharge its contents readily by tipping backward. The hind axle is deeply cranked forward so as to clear the body of the wagon when the latter is tilted. The wagon body is pivoted a little behind the centre of gravity, and when in the horizontal position is locked by a lever in the front. Inv. 1857–19.

744. Woodcut of Adams's omnibus, 1847. Presented by R. B. Prosser, Esq., 1914.

This omnibus was patented by Mr. W. B. Adams in 1846, and seems to have been the first having a roof with a raised central portion which was to be utilised as a double seat for outside passengers; this improvement, however, does not appear to have been generally adopted until some ten years later. An intermediate design, with a low board along the centre of a slightly curved roof, seating five persons on the off side, was in use about 1848, and this was probably the origin of the term "Knifeboard," as applied to an omnibus, a name which was afterwards applied to the later type also. Inv. 1914-433.

745. Model of brougham. (Scale 1 : 6.) Made by James Reid, Esq. Received 1906.

This model shows the construction of a pair-horsed double-seated brougham, the materials being left in their natural colours and the upholstery omitted so that the details may be seen. The body is framed in wood and covered with thin panelling, but it is strengthened longitudinally by a vertical steel plate at each side, which follows the lower outline of the body and extends forward to carry the driver's box. The front seat may be tilted up when not in use. The body rests in front on a spring-supported fore-carriage constructed of steel and wood, while at the rear end two projecting bars, firmly secured to the framing, are attached to the springs of the hind axle. The springs are of the modified C form patented by Mr. G. H. Morgan in 1876, with which no perch is necessary. The lower part of each C spring is fastened to the axle and extends beyond it, forming an elbow spring which is coupled to a similar spring above it: this upper spring is bolted to the carriage supports and its other end is suspended from the top of the C spring by a leather link. The vehicle is steered by a pole attached to the fore-carriage, to which the traces are also attached. The wheels have iron tires, and brake blocks are applied to the hind wheels by levers pivoted on the bottom of the body and actuated by a lever at the side of the box. M.3433.

746. Model of landau. (Scale 1 : 6.) Made by James Reid, Esq. Received 1902. Plate XI., No. 3.

In this model, which represents the most general form of pair-horse private carriage, the materials have been left in their natural colours and the upholstering omitted, so that the details of construction can be more clearly seen.

The underframe is chiefly built of steel, and is carried upon the hind axle by elliptical springs, while at the front it rests on a fore-carriage supported on similar springs. At each of the four corners of the underframe projects upward a C spring, from which the carriage body is suspended by adjustable leather straps. The body is framed in wood and covered with thin panelling, but longitudinal strength is given in the middle by a steel plate at each side, set on edge; the attachments for the supporting straps are made of steel bars secured to the body and to these plates, while extending almost to the doorway. The driver's box is carried by a steel framework attached to the body, of which it forms an extension, and side swinging is checked by transverse leather straps, connecting the body with the underframe.

During inclement weather the carriage can be converted into a closed one by swinging upward the two hoods, which meet at the top and form a continuous closed roof and sides, except at the doorways, which spaces may then be completely closed by glass windows that can be pulled upward from recesses containing them in the lower portion of the doors. The work of raising the hoods is facilitated by springs, while when in position they are fixed by a knuckle-joint arrangement that tightens the leather covers.

The vehicle is steered by a pole attached to the fore-carriage, and the pull of the horses is exerted by four traces, also connected with the fore-carriage. The wheels have iron tires, into which cushion tires of rubber are secured.

In the landau represented there is a brake fitted to the hind wheels, capable of being applied by the driver through a wire rope and a pair of levers carrying brake pads and having their fulcra secured to the underframe.

M.3250.

Wheels and Tires.

747. Spare motor wheel. Presented by the Stepney Spare Motor Wheel, Ltd., 1912.

This arrangement, for rapidly replacing a damaged pneumatic tire on a motor vehicle by another already inflated one, was patented by Messrs. T. M. and W. Davies in 1904 and 1906.

It consists of a specially strong auxiliary rim which is clamped on to the outside of the wheel, so that no time need be spent in removing or repairing the punctured tire, but the spare rim and tire may be applied at once. The rim has four hooked clamps fitted to the inner surface, and these grip the beaded edge of the fixed rim. Two of the clamps are fixed, while the other two slide radially in guides, and are adjusted and tightened up by screws and fly-nuts. The spare rim is prevented from creeping round the wheel by a leather link secured to two posts projecting from the rim and passing round one of the wheel spokes.

The example shown is for a tire 815 mm. (32·1 in.) diam. by 105 mm. (4·13 in.) wide. M.4144.

748. Detachable wire wheel. Presented by Messrs. Rudge-Whitworth, Ltd., 1908.

This is a specimen of the detachable wire wheel for motor cars patented by Mr. J. V. Pugh and Messrs. Rudge-Whitworth in 1905–6. By this arrangement the delay resulting from a damaged tire is reduced by removing the whole wheel and substituting a spare one with its already inflated tire.

The wheel consists of a hub shell, formed from two steel stampings, connected with a steel rim by tangential wire spokes. The hub shell fits over a permanent hub running on ball bearings on the axle, and engages with it by means of internal flutings which fit into corresponding flutings cut on the surface of the inner hub. To secure the wheel, a cap, attached to the end of the shell, is screwed into the end of the inner hub and locked by a pawl which enters one of the several notches formed round the edge of the shell. The pawl is held in place by a spring, and a special spanner, provided with a cam

which pushes the pawl out of gear, is used when the wheel is to be removed. A pilot piece is attached to the shell to facilitate the engagement of the flutings. The spokes have thickened ends and pass radially through holes drilled in the hub shell; they are then bent tangentially. The outer spokes have a greater inclination to the plane of the wheel than the inner ones and they pass through the smallest part of the hub; they are intended to give lateral stiffness. The driving stresses are transmitted chiefly through the inner spokes which are shorter and pass through the lip of a large flange formed on the hub.

It is claimed that these wheels are much stronger and lighter than wooden ones, and that a wheel can be changed in 30 sec. The specimen shown is for the front axle of a car and takes a pneumatic tire 870 mm. (34·25 in.) diam. by 90 mm. (3·54 in.) wide. Its weight is 23·64 lb. and that of the inner hub is 3·8 lb. M.3538.

749. Resilient wheel and tire. Lent by the Lynton Wheel and Tyre Syndicate, Ltd., 1912.

This is an example of the wheel for motor vehicles patented by Mr. R. T. Smith in 1905–6 and 1908. The wheel is of steel, and the tire is of solid rubber, but they are so constructed that they act somewhat in the manner of a pneumatic tire; the cushioning effect is obtained by the lateral displacement of parts of the tire, and not by direct compression of the rubber, and the stress in the part of the tire in contact with the road is transferred to the opposite part of the circumference.

The tire is formed of a number of rubber sectors, each having a deep tread portion and a two-lobed base which fits the wheel rim. Spaces are left between the sectors, and these assist in preventing side-slip. The wheel consists of a conical steel disc fixed to one end of the hub shell, and stiffened against lateral stresses by a similar disc fixed to the middle of the hub, and riveted to the first disc near its circumference; at the other end of the hub is a loose conical disc which rocks on a spherical nut screwed on the hub. The discs are stamped and pressed to a spoked form, and the edges of the two outer discs are curved to fit the lobes of the tire sectors so as to hold them securely in place when the hub nut is screwed up; flanges projecting from and riveted to the fixed disc fit between the tire sectors and prevent creeping. The load on the wheel, or an obstacle on the road, displaces the lobes at the lowest point of the tire, causing the loose disc to rock and compress the tire at the highest point. The ball joint is covered by a cap. The example shown is 30 in. diam. M.4013.

750. Motor-car wheel with detachable rim. Presented by the Shrewsbury and Challiner Tyre Co., Ltd., 1910.

In order to avoid tire repairs on the road, and the consequent delay, it is now the practice to carry a spare wheel or rim, fitted with an inflated tire, which can be used to replace the damaged one. The example of detachable rims shown was patented by Messrs. C. S. and J. A. Challiner in 1906–7, and it permits the use of any ordinary rim.

It consists of a steel rim of deep channel section, which is shown fixed to a wooden wheel, but is equally suitable for wire wheels. This channel has its edges bevelled outwards while one side is made separate and is secured by six transverse bolts. The bevelled edges grip the rim to which the inflated tire is attached, the security bolts being accommodated in the deep channel. In order to facilitate the removal of the loose ring, the bolt holes in it are much larger than the bolts, and the nuts are provided with tubular extensions fitting the holes. The bolts are held in position by wooden blocks clipped to the fixed rim, while another block surrounds the tire valve and receives two registering pins fixed to the tire rim.

The wheel has ash felloes and ten oak spokes with wedge-shaped ends, fitted closely together and bolted between the steel flanges of the hub. The tire is 750 mm. (29·5 in.) diam. by 85 mm. (3·35 in.) wide. M.3766.

751. Pressed steel motor car wheel. Lent by Messrs. Joseph Sankey & Sons, Ltd., 1911.

This is an example of the pressed steel detachable wheel of the construction patented by the makers in 1908 and 1910.

The wheel is made in two pieces, each pressed out of a circular plate, the spokes being formed, and the edges being folded and bent so as to form a rim suitable for holding a pneumatic tire. The two parts are then welded together at their edges, which meet on the central plane of the wheel, a hollow steel stiffening boss having been inserted previously between the discs. A steel plate with five driving pins, which pass through the wheel, is bolted on, and these pins engage with holes in a disc attached to the hub. The wheel has a central hole with bevelled edges, and fits on a conical part of the hub, where it is secured by a screwed cap which is prevented from slacking back by a pawl, fitted in the cap, and ratchet teeth cut on the hub. A special spanner is used, which disengages the pawl before unscrewing the cap, and a bolt is provided for positively locking the pawl in the ratchet teeth when the cap is screwed up. The pawl must be unlocked before the cap can be unscrewed, and it must be locked again, after screwing on the cap, before the spanner can be removed from the hub.

The example shown is for a tire 760 mm. (29·9 in.) diam. by 90 mm. (3·54 in.) wide; the wheel alone weighs 18 lb. M.3988.

752. Detachable rim for motor-car wheel. Presented by the Warland Dual Rim Co., 1913.

This is a motor wheel of the artillery pattern fitted with the dual rim patented between 1908 and 1911 by Mr. P. W. Turquand, Mr. S. H. Cope, and others.

The rim is in two parts. The outer one, supporting the tire, is made with a segmental gap piece, which can be taken out by slightly expanding the rim with the tool shown. With the same tool the rim is then contracted so as to put on or take off easily the beaded edge cover. The outer rim and segment are gripped close up to the edges by the inner rim on one side and an annular flange on the other held by transverse bolts.

The air valve is protected by a cover held on from the nave by a screwed strut and lock nut.

The rim is for a tire 815 mm. (32·1 in.) diam. by 105 mm. (4·1 in.) wide; the whole wheel weighs 57·4 lb. Inv. 1913–165.

753. Model of motor-car wheel with detachable rim. (Scale 1 : 2.) Lent by the Captain Rim Co., Ltd., 1914.

This form of detachable rim, for motor-car wheels, was patented by Mr. A. F. Gunstone in 1909 and 1910. It is shown fitted to a wire wheel.

A steel rim of ordinary form, to which the tyre is fitted, is provided with an inward projecting flange on the outer side, the inner part of the flange forming a step on the inner surface of the rim. The wheel rim is made of channel form, the inner flange being deeper than the outer one, so that the tire rim will fit over it. The rim is a very tight fit on the wheel, and it is drawn on by six bolts passing through holes in the flange and entering long nuts fixed to the channel rim. The valve hole is made large to facilitate fitting, and a security valve bolt is provided in place of the ordinary bolts. The tire rim is removed by screwing one of the holding bolts into a tapped boss fixed to the flange diametrically opposite the valve, the point of the screw bearing on the channel rim. A brace is provided for manipulating the bolts. The model shown represents a wheel for a tire 815 mm. (32·1 in.) diam. by 105 mm. (4·13 in.) wide. Inv. 1914–686.

754. Motor-car wheel with solid rubber tire. Presented by the Shrewsbury and Challiner Tyre Co., Ltd., 1910.

This is a wooden wheel of the artillery pattern fitted with a solid rubber tire, which is secured in the manner patented by Mr. C. S. Challiner in 1909; it is suitable for commercial or other motor vehicles.

The rubber tire has a rounded tread, and is vulcanised to an iron band, which is pressed on over the binding ring that surrounds the felloes of the wheel. A steel ring is bolted at each side of the rim to secure the tire laterally. The wheel has 12 oak spokes and ash felloes; the tire is 30 in. diam. and 3 in. wide. M.3765.

755. Thomson pneumatic tire (1845). Lent by the Dunlop Pneumatic Tyre Co., Ltd., 1910.

This is a specimen of the original pneumatic tire patented by Mr. R. W. Thomson in 1845. Such tires were made and tried on ordinary carriages, and their capability of absorbing vibration and shocks was recognised, while tests proved that the tractive force required to draw a carriage so fitted, especially on rough roads, was greatly reduced. The idea was, however, soon dropped, probably on account of imperfect construction, and because the advantages at low speeds were not sufficient to counterbalance the cost of the large tires used. On the advent of the safety bicycle, the idea was independently revived and re-patented in 1888 by Mr. J. B. Dunlop (*see* No. 801). The pneumatic tire is now used generally on cycles and motor cars, but only to a small extent on horse-drawn vehicles.

The tire shown has an airtight inner tube made of canvas and rubber, and provided with an orifice for the admission of air; this tube is surrounded by a leather casing built up of sections sewn together. The wheel is of wood and has a rim 7·5 in. wide, with a flat iron tire; the leather cover is laid open upon this and bolts are passed through it and the rim to secure it. The air tube is then laid on the cover, the two edges of which are turned over to enclose it, overlapped and riveted together. In another construction, the leather cover was in two halves, one of which was bolted to the rim while the other was riveted to the first along one edge, turned over to embrace the inner tube, and laced along the other edge. The tube could thus be removed after unlacing the cover. Subsequently the outer cover was made of canvas, and provided with a rubber wearing band on the tread.

The wheel shown is 47 in. diam., over the iron tire, while the air tire when inflated would be about 6 in. diam. M.3732.

756. Pneumatic tires for motor cars. Lent by the Dunlop Pneumatic Tyre Co., Ltd., 1910.

Pneumatic tires are considered essential for passenger motor cars, not only on account of the comfort of the occupants and the higher speeds attainable, but also on account of the great reduction in the wear and tear of the mechanism, due to the absorption of vibration and shocks by the tires. Their cost is, however, high.

Practically all motor tires are now of the beaded-edge pattern and are held in place, not only by the beads fitting under the edges of the rim, but also by a number of chaplet-headed bolts which pass through the rim of the wheel and are tightened by fly-nuts. The specimens shown have red rubber air tubes about 0·125 in. thick. The covers are built up of several layers of strong woven fabric, embedded in rubber, and covered with a thin layer of rubber, which is supplemented by a thick tread that may be removed when worn, and replaced by a new one.

No. 1 is a light tire with a cover composed of four layers of fabric covered with rubber; the rubber tread, 0·25 in. thick, is plain and has one layer of fabric incorporated with it. The cover is 65 mm. (2·56 in.) diam., 0·18 in. thick at the sides and 0·48 in. thick at the tread. The tire will carry a load of 360 lb. with an air pressure of 50 lb. per sq. in.

No. 2 has a cover composed of six layers of fabric. The tread is of rubber, 0·25 in. thick, with four layers of fabric embedded in it; this is provided with three circumferential rows of projecting steel studs, riveted into it, for the prevention of skidding. The tire is 105 mm. (4·13 in.) diam., its sides are 0·3 in. thick, and the tread 0·68 in. thick.

No. 3 has a cover lining similar to No. 2, but the rubber coating is thickened at the tread and has two layers of fabric embedded in it; to this is attached a leather tread band, 0·15 in. thick, in which are riveted four rows of non-skid studs. The cover is 105 mm. (4·13 in.) diam., its sides are 0·3 in. thick and its tread 0·65 in. thick. No. 2 or No. 3 will carry a load of 1,050 lb. with an air pressure of 80 lb. per sq. in.

No. 4 is a heavy plain tire with a cover having seven layers of fabric, and a rubber tread, 0·55 in. thick, having a band of fabric inside it. The tire is 135 mm. (5·32 in.) diam., its sides are 0·35 in. thick and its tread 0·95 in.

No. 5 is similar to No. 4 except that the rubber tread is 0·6 in. thick and has transverse grooves formed in its surface to prevent skidding. The cover is 135 mm. (5·32 in.) diam., 0·35 in. thick at the sides and 1 in. thick at the tread. No. 4 or No. 5 will carry a load of 1,400 lb. with an air pressure of 85 lb. per sq. in. M.3741–5.

757. Sections of pneumatic motor car tires. Presented by the Palmer Tyre, Ltd., 1910.

These are five sections showing different sizes of the Palmer cord tire, introduced in 1903. In this tire the cover is built up of two layers of a continuous cord, composed of several strands thoroughly saturated with rubber, and wound on a former so as to constitute a diagonal parallel thread fabric similar to that used for cycle tires (*cf.* No. 803). The layers are wound in opposite directions so as to cross one another at about right angles. In the larger sizes the cord is flat instead of circular, so that it will lie flat on the tread, and be placed on edge at the rim, and thus the adjacent threads will fit closely together all round. The cord is passed round steel staples, fixed in a canvas foundation ring, and these are incorporated in the beaded edge, thus strengthening it. A coating of rubber with a thick tread formed into three circumferential ridges is applied, and the whole vulcanized; the smallest section has also an inner rubber pad which prevents the cover from being bent at too sharp an angle. The cord was originally wound by hand, but this operation is now performed by special machines. The security bolt heads are covered with rubber and canvas in order to prevent injury to the air tube. M.3764.

758. Reinforced outer cover. Presented by Messrs. Stelastic Tyres, Ltd., 1913.

This is a motor tire cover, the tread of which is reinforced by a fabric of interlaced spring wire helices filled with rubber and vulcanized in position, as patented in 1910 by Mr. A. E. Wale. The elasticity of the steel and of the rubber is analogous, and it is stated that disintegration does not occur. Safety from punctures, prevention of skidding and durability are claimed.

A section of an outer cover 820 mm. (32·28 in.) diam. by 120 mm. (4·72 in.) wide and a piece of the "stelastic" fabric are shown.

Inv. 1913–177 and 189.

759. Inner tubes for pneumatic tire. Presented by the Searle Unburstable Inner Tube Co., 1913.

This inner tube for pneumatic motor tires, patented in 1909 and 1911 by Mr. T. H. Hall has a layer of fabric embodied in the walls. To give the necessary elasticity for inflation, there is a pleat, arranged on the tread, filled up before vulcanization, with a wedge-shaped rubber strip. The tube will not burst if the outer cover suffers a gash, and a saving in upkeep is claimed.

Sections of 85 mm. (3·34 in.) diam. and of 120 mm. (4·72 in.) diam. tube, together with a piece showing the valve seating, are exhibited.

Inv. 1913–173 to 174.

760. Section of "Pfleumatic" tire. Lent by the Dunlop Pneumatic Tyre Co., Ltd., 1911.

Pfleumatic is a tire-filling compound which is introduced into the cover of a tire in place of the air-filled rubber tube, in order to produce a non-puncturable tire having much of the resilience of the pneumatic; it was patented by Herr F. Pfleumer and others in 1906, 1908 and 1909.

The materials, consisting mainly of gelatine and glycerine, are heated in a boiler, and, when under high compression, the mixture is stirred into a froth which is pumped into the tire cover, where it coagulates. The resulting product is a spongy rubber-like material containing numerous hermetically sealed cells which are filled with compressed air; the puncturing of a few of these cells does not affect the tire, and the cover can be worn almost through without danger. A channel-shaped steel band is placed round the rim, inside the cover, in order to enclose the filling completely.

The weight of an 815 mm. (32·08 in.) by 105 mm. (4·13 in.) tire is increased about 20 per cent. when so filled. The substance may also be used for other purposes, such as stuffing cushions, etc. M.3811.

761. Section of solid band tire. Presented by the North British Rubber Co., Ltd., 1913.

Solid rubber tires were first applied to traction engines by Mr. R. W. Thomson in 1868, and the problem of securely attaching them to heavy motor vehicles has, after the trial of many devices, been simply and satisfactorily solved by the band type of tire. In this, the rubber is vulcanized on to a massive steel band, which is forced on to the rim of the wheel by hydraulic pressure. A section of a 4 in. band tire is shown.

The band has wide shallow circumferential grooves cut on its outer surface, and the whole surface in contact with the rubber is scored with fine V grooves. The band bears on the rim at the two edges only, the space between being covered with a thin layer of rubber. M.4261.

762. Sections of solid clincher tires. Presented by the North British Rubber Co., Ltd., 1913.

In the application of solid rubber tires to motor vehicles, great attention has to be paid to securing them on the wheel rims in such a manner that they shall not creep or slip off. For the lighter vehicles, the clincher type of tire and rim, patented by Mr. W. H. Carmont in 1881, has been found efficient, and two sections of 3·5 in. and 4 in. tires of this type are shown.

The tire itself is formed with a wide base, the sides of which are forced under the curled edges of a steel channel rim previously bolted or screwed to the felloes of the wheel. A strip of canvas is vulcanized on to the inner surface of the rubber, and this provides a good frictional grip and prevents the rubber next the rim from stretching. M.4260.

763. Portable tire vulcanizer. Lent by Messrs. Harvey Frost & Co., Ltd., 1912.

The practical success of the pneumatic tire on motor cars has been due, to no small extent, to the introduction by Mr. H. H. Frost in 1902, of a portable vulcanizer, by means of which damaged tires can be repaired easily in such a way that the repair is a re-make of the damaged part, which then forms an integral portion of the tire, without damage to the surrounding material. The process is exactly that used in the manufacture of the tire, and consists in the application to the damaged part of a plastic rubber-sulphur mixture, which is then vulcanized by steam heat. The example

shown is a small vulcanizer which can be carried on the car, and may be applied directly to a tire without removing it from the wheel.

The apparatus consists of a steam boiler heated by a spirit lamp. The body of the boiler is a gunmetal box casting having four vertical flue tubes through it; one side of the body is hollowed out to fit an outer cover, while the opposite side is flat for use with the inner tubes. The lamp fits into the bottom of the boiler, and the flame can be adjusted by a sliding tube; a pressure gauge is used to indicate the pressure of the steam, and consequently its temperature. A safety valve and filling plug are provided. When repairing an outer cover, the vulcanizer is clamped to the tire by a chain passed round the wheel rim, and tightened up by a screw and fly-nut. When repairing an inner tube, the damaged part is placed on the flat side of the vulcanizer, and held in close contact by a screw-clamp with suitable pads. The various tools used are shown with the vulcanizer.

The process of repairing holes in a cover or tube is shown by adjacent specimens. The edges of the cut are first bevelled, roughened with a file, and coated with a special flux. The plastic rubber mixture is next inserted in the cavity, well pressed in, and trimmed level. The damaged part is then placed in close contact with the vulcanizer, the steam being at a pressure of 45 lb. per sq. in., and kept there for the necessary length of time, varying, according to the thickness of the material, from 7 to 25 minutes. M.4164.

Cycles.

764. Reproduction of hobby horse. Presented by H.G. the Duke of Northumberland, K.G., 1904. Plate XI., No. 4.

The hobby, or dandy-horse, the forerunner of the bicycle, was patented in France by Charles, Baron von Drais, in 1818, and in the same year was introduced into England by Denis Johnson, a coachmaker of Long Acre, who took out a British patent for it, in which he described it as a "Pedestrian Curricle." Its use became a recreation for some time, but called forth much ridicule, which its merits did not enable it to survive.

The machine consists of a wooden bar, or backbone, strengthened by iron and supported by means of light ironwork upon two wheels, arranged one behind the other, the front one being mounted on a fork socketed in the front end of the backbone. It was propelled by the rider, who, while astride of the saddle on the backbone, and leaning his elbows on the well-padded support, scuffed backward upon the road with the right and left foot alternately, at the same time maintaining the balance of the machine by steering by means of the handle bar which, as in the modern bicycle, is fixed to an extension of the front fork; the earlier steering arrangement is shown in the prints. A stay-rod linked to the backbone was provided to retain the machine upright when not in use. The speed attained was as much as 10 miles per hour on the level.

The machine shown is a reproduction of one preserved at Alnwick Castle, and has equal wheels 29·3 in. diam., and a wheel base of 41 in.; it weighs 52 lb. M.3334.

765. Engravings of hobby or dandy horse. Received 1902.

The machine represented in these prints is the original form of the bicycle. It is similar to No. 764; but although the steering fork was pivoted in the front of the backbone, instead of being continued through it to receive the steering handle, the handle was connected with the fork by a long bent rod brought upward from the front of the fork.

The upper engraving is modern, having been prepared in 1894, but the lower one was published in 1819, and shows the interior of Johnson's Riding School, where the use of the machine was taught. One of the riders is represented as "coasting," which was the recognised way of descending hills; when, however, a hill had to be ascended, it appears to have been usual to carry the machine on one shoulder.

A modification of the hobby horse was introduced about 1819 for the use of ladies, and it had the downward curved backbone or drop-frame now general in ladies' bicycles. The weight of a hobby horse was about 50 lb., and the price was from 8*l.* to 10*l.* M.3251.

766. Early bicycle. Received 1907. Plate XI., No. 5.

This machine marks the first step in the development of the bicycle from the hobby horse. It was invented in 1839 by Kirkpatrick Macmillan, a blacksmith, of Courthill, Dumfriesshire, who seems to have been the first to discover that two wheels placed in line could be balanced and could be propelled by treadles and cranks fitted to one of the axles. Macmillan allowed his machine to be extensively copied but it does not appear to have become very popular, although it anticipated the rear-driving safety bicycle of forty years later. This specimen, which came from Scotland, is probably one of these copies, made about 1860 by Thomas McCall, slightly modified by the addition of a brake.

The machine has wooden wheels with iron tires, and the frame consists of a curved wooden bar, forked to embrace the rear-driving wheel and carrying the axle bearings near its end. The steering wheel is carried in an iron fork the pivot of which passes through the frame and has the handle bar attached above. Both axles run in brass bearings. The rear axle has cranks keyed to its ends and these are driven by connecting rods, from intermediate points in two swinging levers, pivoted near the steering head and carrying wooden treadles at their lower ends. The saddle is mounted on a spring bolted to the frame and is at such a height that the feet of the rider could be easily placed upon the ground. The brake is a wooden plunger applied to the rear wheel by a cord which can be tightened by rotating the handle bar. At the front end of the frame is a carved representation of a horse's head. An iron guard covers the rear wheel behind the saddle.

The front wheel is 32 in. diam., the rear one 42·5 in. diam., and the wheel base 48 in. The cranks are 6·25 in. long and the treadle stroke is increased by the levers to 17·6 in. The machine weighs 57 lb. M.3505.

767. Velocipede. Lent by H.M. King Edward VII., 1901.

This rear-driven front-steering quadricycle belonged to H.R.H. Prince Consort, for whom it was made, probably about 1851, by Mr. J. Ward, a coachbuilder in Leicester Square, W.C. A very similar machine had been constructed about 1819 by the Rev. Edmund Cartwright, and many other forms of "pedomotive carriage," or velocipede, were built at various periods, but after the introduction of the bicycle the more expensive and cumbrous arrangement became of but secondary interest.

The velocipede shown has a frame of solid iron carrying a cushioned seat; the rear axle turns in bearings attached to the frame, while the fore-carriage is connected by a swivel-plate and central bolt. The rear axle is bent into two opposite cranks, which are driven by treadles attached to them and suspended by links from the front extension of the frame; the rider's feet are held by straps to clogs adjustably secured to the treadles. The vehicle is steered by a single hand-lever connected with the fore-carriage.

The wheels are of wood with iron tires; the front wheels are 34 in. diam., the driving wheels 40 in. diam., the crank radius 7·75 in., but the semi-vertical motion of the clogs is only about 4 in. The total weight of the machine is 115 lb. M.3196.

768. Early bicycle. Presented by Killingworth W. Hedges, Esq., 1905. Plate XI., No. 6.

This form of bicycle, now known as a "boneshaker," was brought out in France in 1865–6 by Mons. Pierre Lallement, and was introduced into this country two years later.

The example shown was made by Mr. Hedges in 1869, and the lamp was fitted the following year. The frame is of solid wrought iron and the wheels of wood with iron tires. It is driven by triangular pedals of wood fitted to cranks on the front wheel, while the rider sits on a saddle mounted on a plate spring supported at one end by the socket head and at the other by struts from the back wheel bearings. Steering is done by a handle bar at the top of the fork, and a brake on the tire of the hind wheel is applied by a cord which can be tightened by rotating the handle bar. Leg rests, which provide supports for the hocks when "coasting," are carried by a forward extension of the backbone, and these, together with the saddle, are fitted with rubber padding.

The front wheel is 36 in. diam. and the back one 30 in. The crank arms have two pedal holes, giving lengths of 5·75 and 7·5 in. respectively. The machine weighs 68 lb. M.3140.

769. "Phantom" bicycle. Presented by A. Markham, Esq. per "*Cycling*," 1901.

This machine embodies improvements patented in 1869 by Messrs. W. F. Reynolds and J. A. Mays, the most important of which is the substitution of wire spokes, in tension, in place of rigid spokes acting as struts. The suspension wheel constructed with leather straps or cords was, however, patented by Mr. G. F. Bauer in 1802, while the iron-spoked wheel for ordinary vehicles was patented by Theodore Jones in 1826, but the "phantom" wheel was the first application of the type to the bicycle.

The wheel has a wooden rim, with eyes screwed into it, and each spoke starting from one end of the hub is passed through an eye and bent so as to return to the other end. The ends of each double spoke were clamped between flanges, and the requisite tension was given by wedging open the rim, which was butt-jointed, or by spreading the two flanges on the hub. The rim was provided with a solid rubber tire stapled to it. The framing is of iron rods, forming two triangles hinged together at their common base; each half is controlled by rods from the steering handle, so that the machine is a double-steerer.

The front wheel is 34 in. diam. and the back one 30 in.; the machine weighs 53 lb. M.3178.

770. Rudge ordinary bicycle. Presented by Messrs. Rudge-Whitworth, Ltd., per "*Cycling*," 1901.

This machine was built in 1884, and represents the then accepted type of directly-driven high machine; it was used by Howell in numerous races, and was exceptionally light, weighing only 21·5 lb. The large wheel is 58 in. diam. the small one 16·2 in., and the cranks are 5 in. long. M.3181.

771. Early safety bicycle. Lent by T. E. Osborne, Esq., 1907.

This is a specimen of the rear-driving safety bicycle patented by Messrs, H. J. Lawson and J. Likeman in 1876. The first bicycle made by Kirkpatrick Macmillan in 1839 (*see* No. 766) was a very similar crank and lever driven machine.

The machine has a large driving wheel and a smaller steering wheel in front of it, the saddle being placed between them at such a height that the rider's feet could easily touch the ground. The wheels are held in vertical forks connected by a frame consisting of two tubular members. Adjustable cranks on the rear axle are driven by connecting rods from the upper arms of bellcrank levers whose lower arms carry the pedals. The wheels have wire spokes and solid rubber tires, and the axles are fitted with roller bearings. The driving wheel is 50 in. diam. and the steering wheel 28 in. The pedals have a mean stroke of 11·5 in. and the machine weighs 66 lb. M.3492.

772. Dublin tricycle. Presented by Mrs. E. Geoghegan, 1913.

When the bicycle had attained some degree of popularity, the need for a more stable vehicle, that would remain upright when at rest, led to the production of the tricycle. The earliest form, introduced about 1870, and known as the "German" tricycle, was evolved from the "boneshaker," the rear wheel of which was replaced by a pair of wheels running loose on the ends of a transverse axle. This machine was unsafe and was little used, and it was only on the advent of the improved "Dublin" and "Coventry" machines that the tricycle came into anything like general use. The "Dublin" tricycle, which was one of the first practically successful machines, was patented by Mr. W. B. Blood in 1876.

The tricycle has a large rear driving wheel and two small steering wheels, placed in front, and mounted in separate forks. The main frame consists of a horizontal U tube to the front points of which the steering wheel fork sockets are attached, while a pair of tubes project backward from the cross-bar and form a fork for the driving wheel. The frame is trussed vertically and diagonally with adjustable tie bars and a wooden strut in front of the driving wheel. The steering forks are inclined and their heads are connected by a link and levers forming an Ackermann steering system. The seat is mounted on two bars swivelling on the cross-bar of the main frame, and has two helical springs at the rear. The rear wheel is driven by cranks fitted on the ends of its spindle and connected by rods with levers pivoted low down beneath the frame; the upper ends of the levers are provided with wooden treadles and iron heel rests.

The driving wheel is 38 in. diam.; the steering wheels are 23 in. diam., and the track width is 32 in. M.4183.

773. Bicyclette. Presented by H. J. Lawson, Esq., per "*Cycling*," 1901.

This machine, which was patented by Mr. Lawson in 1879, marks an important step in the evolution of the present rear-driven safety bicycle. The rear wheel is increased and placed further back, so leaving room for what is now called the crank bracket, and the power is transmitted from the cranks to the rear wheel by a pitch chain. The saddle is so far back that steering is performed by a handle-bar connected with the front fork by a nearly horizontal link.

The front wheel is 40 in. diam. and the back one 24 in., but it is geared to 40. The weight of the machine is 60 lb. M.3179.

774. "Otto" di-cycle. Presented by the Viscountess Sherbrooke, 1901.

This form of bicycle was patented in 1879–81 by Mr. E. C. F. Otto, and the example shown, which was regularly used by the late Lord Sherbrooke, was built by the Birmingham Small Arms Co. about 1881. The Otto cycle soon became somewhat popular, as it was considered less dangerous than the ordinary high bicycle, but the subsequent development of the safety bicycle led to its complete abandonment.

The machine has two large road wheels, both loose on a straight axle which supports the saddle and the entire framing, but from the back of the frame projects a bar carrying a small rubber-tired roller, which prevents the frame and rider from swinging too far backward, and also can be used as a trailing brake, although normally it is well clear of the ground. Projecting downward in front of the axle are two telescopic rods which support the bearings of a double-throw crankshaft provided with pedals by which the shaft is rotated. At each end of the crankshaft is a rubber-sheathed pulley, which, by a steel band fitted with transverse driving ribs, drives a similar pulley attached to its corresponding road wheel; in this way both wheels are driven at uniform speed. On each side of the rider is a steering handle fixed to the axle, and connected with the crankshaft bearing in such a way that either

driving band can be slackened so that its road wheel becomes free; these steering handles each contain another handle by which a band brake can be applied to a drum on its road wheel. By these arrangements either road wheel can be driven or checked in a way that enables the machine to be indirectly steered. The driving bands are normally kept at the necessary tension by a spiral spring in each of the telescopic legs.

The driving wheels are 56 in. diam., and are 32 in. apart at their tires, which are of solid rubber; the crank radius is 6 in. and the total weight of the machine is 95 lb. M.3198.

775. "Rover" bicycle. Presented by J. K. Starley, Esq., per "*Cycling*," 1901.

The "Rover" bicycle, invented by Messrs. Starley and Sutton in 1885, embodied most of the features of the present safety machine, and was the bicycle which practically introduced and rapidly demonstrated the superiority of the safety arrangement. The example shown is the second made, and is that upon which Golder rode in the 100 miles race in 1885. The steering head slopes, as at present, but the forks have no set, and the frame is in no sense triangulated.

The front wheel is 32 in. diam. and the back one 30 in., but geared up to 60 in. The cranks are 6·5 in. long, and the machine weighs 37 lb. M.3180.

776. "Kangaroo" bicycle. Lent by T. E. Osborne, Esq., 1907.

This is a dwarf front-driving machine patented by Mr. W. Hillman in 1884, and constructed by Messrs. Hillman, Herbert and Cooper about that time. It has a small front wheel driven by cranks placed some distance below its centre and connected with it by chains. The fork is raked and continued downward to support the divided crank-axle bearings; there is a chain on each side of the wheel. The centre of the wheel is in front of the fork, and the bearings slide along it to adjust the chains. The machine is fitted with ball bearings, a spring saddle, and a spoon brake.

The front wheel is 36 in. diam., but is geared to 54 in. The cranks are 6 in. long, and the machine weighs 48 lb. M.3493.

777. "Geared facile" bicycle. Lent by T. E. Osborne, Esq., 1907.

This machine, made by the Crypto Cycle Co. about 1888, illustrates one of the attempts made to render the front-driving bicycle safer. This was accomplished by using a smaller driving wheel geared up by sun and planet wheels, and by raking the front fork and thus placing the mass-centre of the rider further behind the wheel centre.

The crank-axle runs in bearings within the hub and is driven by connecting rods attached to the middle points of vibrating pedal levers, which are pivoted on forward extensions of the fork. One connecting rod carries a planet pinion which gears with a sun wheel keyed to the hub. Ball bearings are fitted to both axles. The driving wheel is 40 in. diam., but is geared to 60 in.; the pedals have a stroke of 12 in. and the machine weighs 37 lb. M.3494.

778. Humber safety bicycle. Presented by Messrs. Rudge-Whitworth Ltd., per "*Cycling*," 1901.

This machine, introduced in 1888 by Messrs. Humber & Co., embodies the chief feature of the now general diamond frame which, however, only took its present shape about 1890.

The machine was called a "dwarf roadster," and has the front wheel considerably smaller than the rear or driving wheel, a peculiarity that was soon abandoned for equal wheels or else a slightly larger steering wheel.

M.3182

779. Singer safety bicyle. Presented by P. G. Betteridge, Esq., 1911.

This bicycle, made by Messrs. Singer & Co., about 1890, embodies improvements patented in 1888 and 1890. It shows the application of the curved front fork, which was patented by Mr. G. Singer in 1878, and was designed so that the steering axis passed through the point of contact of the tire and the ground, thus improving the steering of the machine. The machine shows also a stage in the development from the Humber open diamond frame of 1888 to the now generally used diamond frame (*see* No. 781). The improvement consisted in straightening the main tubes and triangulating the frame by the addition of a curved down tube from the saddle to the bottom bracket; this tube was curved because the driving wheel was placed as close as possible to the crank bracket, in order to keep the wheel base short. The crank bracket is made separately and bolted to the lower joint of the frame. A head lock is fitted to the steering wheel, the pedals are of rubber, and mudguards are fitted to the wheels. The machine is fitted with cushion tires and with a plunger brake on the front wheel.

Both wheels are 30 in. diam., and the driving wheel is geared to 57 in.; the cranks are adjustable from 6 in. to 6·75 in.; the machine weighs 48 lb.

M.3847.

780. "Bantam" bicycle. Lent by T. E. Osborne, Esq., 1907.

This machine, made by the Crypto Cycle Co. about 1893, was the last machine of the geared ordinary type to survive. It has a very small front driving wheel which is geared up by means of an epicyclic train, this "Crypto" gearing having been introduced into these machines by Messrs. T. Shaw and A. Sydenham in 1891.

The framing consists of a front fork and a single curved tube with a vertical pillar carrying the saddle. The gearing consists of a sun wheel fixed to the hub, four planet pinions carried by a disc attached to the crank, and an outer internally toothed ring fixed to the fork. Thus for every revolution of the crank the wheel makes 2·75 turns. The machine is fitted with pneumatic tires and the plunger brake pad is in the form of a brush.

The driving wheel is 24 in. diam., but is geared to 66 in. The rear wheel is 20 in. diam., the cranks are 6·5 in. long, and the machine weighs 28 lb.

M.3495.

Cycle Details.

781. Pressed steel cycle parts. Presented by the Raleigh Cycle Co., 1911.

These are specimens of various parts of the Raleigh "all-steel" bicycle, which are made as steel stampings. Especially noteworthy are the frame lugs, crank bracket and fork crowns, which are pressed out of sheet steel, instead of being made of malleable iron castings, as was formerly done; the fork sides, back and chain stays are also pressed out of sheet steel. The edges of the plates are afterwards welded together where necessary. A complete frame, with the joints in section, is shown; the joints are strengthened with internal liners and pins, and are brazed by dipping them into a bath of molten metal.

M.3823.

782. Ratchet clutch. Presented by A. J. Wilson, Esq., per "*Cycling*," 1901.

This is shown as fitted to one of the hubs of a "Devon" front-steering double-driven tricycle. It was patented in 1879 by Mr. F. W. Jones as a means of facilitating passing round curves; the two driving wheels were independently driven from the crankshaft by chains, and the ratchets allowed the outer wheel to overrun when turning a corner. These clutches, however, converted the driving mechanism into a "free wheel" arrangement. Each clutch has two opposite pawls, which engage simultaneously. M.3184.

783. Roller clutch. Presented by the Swift Cycle Co., per "*Cycling*," 1901.

This is from the driving axle of a "Cheylesmore" double-driven rear-steering tricycle, built by the Coventry Machinists' Co. about 1881.

The sprocket wheel is loose on the shaft, but within it is a six-sided steel cam keyed to the shaft. Between the cam and the wheel are six short rollers, which jam the two together when going in one direction, but leave them free in the other. This clutch was patented by Messrs. J. White and G. Davies in 1881, but it resembles that used in Otto and Langen's gas engine of 1866 (*see* No. 433).

This arrangement was provided to allow the outer wheel of the tricycle to turn in advance when passing round a curve, but it also gave a "free-wheel" drive. To allow of back-pedalling, the sprocket wheel was also fitted with a ratchet-faced clutch, which was automatically thrown out of gear by the steering handle. M.3183.

784. Roller clutch. Presented by Messrs. Humber Limited, per "*Cycling*," 1901.

This clutch was made by Mr. Thomas Humber, and appears to have been intended for the front axle of an "ordinary" bicycle, which would thus be given a free wheel. It resembles the Cheylesmore roller clutch (*see* No. 783), and is probably of about the same date. M.3185.

785. Early ball bearing for bicycle. Presented by Messrs. Humber Limited, per "*Cycling*," 1901.

This shows the construction adopted by Mr. Thomas Humber about 1880 for reducing the friction of the back wheel hub of an "ordinary" bicycle.

The inner faces of the fork and the outer faces of two collars on the spindle have each cut in them a semi-circular groove, so that steel balls can be inserted which will carry both the vertical and lateral pressures. The arrangement is adjustable for wear. M.3186.

786. Bush roller cycle chain and sprockets. Presented by Messrs. Hans Renold, Ltd., 1911.

Pitch chains have been used for many years for driving purposes, largely in textile machinery, and the bowl or roller chain was patented by Mr. J. Slater in 1864. Modern improvements in chain construction have been largely due to the invention of the chain-driven safety bicycle in 1879, and the examples shown are of the form patented by Mr. H. Renold in 1880, 1891 and 1899.

The chain is made up of pairs of steel plate links having bevelled edges and a hole at each end, connected together by rivets, with spaces between them for the accommodation of the sprocket wheel teeth. The alternate pairs of links have hardened steel solid bushes forced into their end holes, hardened steel rollers being placed over the bushes, with sufficient end clearance to permit of their rotation. The rivets also are of case-hardened steel with shouldered and slightly countersunk ends; these are passed through the bushes and the outer link plates forced on to their ends, which are slightly expanded by a punch. The bushes distribute the load over the whole length of the rivet, instead of concentrating it under the two inner link plates, thus reducing the wear and consequent increase in pitch. The links are punched out of sheet steel having a tensile strength of 90 tons per square inch; a second light shaving cut is taken to remove small burrs and to make the links true in size and shape, which process facilitates the exact location of the punched holes.

The chain is mounted on a pair of Renold standard sprockets, which are constructed so as to allow the chain to engage properly with the wheel teeth even when its pitch has been increased by wear; this result is obtained by making the pitch of the teeth on the driving sprocket slightly greater than

the pitch of the chain when new, and providing considerable clearance for the rollers between the teeth. The driven sprockets need the roller clearance only.

The chain is jointed by a loose link which has two elongated rivets fixed in one side plate; these rivets are passed through the bushes of the two adjacent links and a loose plate is placed over their ends, where it is secured by a slotted spring clip which fits into grooves cut round the ends of the rivets.

The example shown has a pitch of 0·5 in. and an inside width of 0·125 in.; its minimum breaking load is 1,850 lb. and the test load 800 lb. It weighs 3 oz. per foot.

An adjacent frame shows the 601 parts which go to make up five feet of such chain. M.3974–5.

787. Collier's two-speed gear. Received 1899.

This is an arrangement patented by Mr. S. J. Collier in 1889, for enabling the rider to change the "gear" of a cycle without dismounting.

A wheel with pin teeth is fixed on the crank axle, and gears by internal contact with a wheel attached to the chain wheel. The crank axle passes eccentrically through a cylinder round which the chain wheel turns, the cylinder itself turning in the bottom bracket. When the low gear is employed a sliding bolt passing through the cylinder is forced by a coiled spring into one of two holes in the pin wheel; the cranks and chain wheel then revolve together.

To change to the high gear the sliding bolt is withdrawn by means of a push piece engaging with an inclined plane on the bolt; this push piece also fits in a slot in the cylinder and prevents the latter from turning. The motion of the cranks is then communicated to the chain wheel through the pin wheel, and as the latter has 20 teeth and the wheel attached to the chain wheel has 17, it follows that for 17 revolutions of the crank the chain wheel makes 20.

To return to the low gear the push piece is pulled out so that the central cylinder is then able to turn, and the sliding bolt is released; the latter springs into the first hole which comes opposite to it as the pin wheel revolves and the cranks and chain wheel again turn together. K.577.

788. Epicyclic gear for a bicycle. Received 1899.

This is the driving mechanism of a safety cycle of the "Bantam" type, in which the front wheel is driven by "Crypto" gearing (*see* No. 780).

A disc fastened to the crank axle carries four pinions which turn loosely upon pins; these pins are riveted at one end into the disc and supported at the other end by a ring. The pinions engage with a wheel fixed on the hub, and also gear into an annular wheel secured to the framework or fork of the cycle.

In the example shown the pinions, the wheel on the hub, and the fixed annular wheel have 12, 32, and 56 teeth respectively; this arrangement causes the hub to make 2·75 turns for every revolution of the crank axle, so that with a front wheel 24 in. diam. the motion is equivalent to that of the "ordinary" cycle with a 66 in. diam. wheel. K.576.

789. Sun and planet gear with oval wheels. Received 1899.

This shows the back wheel of a safety bicycle fitted with the driving mechanism, patented by Messrs. J. Harrison and J. Dodd in 1894.

The pedals are fixed to the ends of levers which are hinged to the ends of oscillating arms, while from near the middle of each lever is a connecting rod passing to a loose crankshaft concentric with the wheel. An oval pin wheel with 24 teeth is secured to one of the connecting rods, and this engages with a pinion of 12 teeth which is attached to the hub of the back wheel, and turns eccentrically round the crank axle; this sun and planet arrangement causes the hub to make three revolutions for one made by the crankshaft.

The oval wheel is so adjusted that the teeth at the end of its minor axis come into action when the pedals are near the ends of their strokes, consequently the pedals move quicker in these positions and slower at the centres of the strokes than would otherwise be the case.

A wire fixed to the framework shows the curve traced by the pedals; the arrow indicates the direction for forward motion and the white lines the distances described in equal intervals. The teeth of the pin wheel have anti-friction rollers; the driving levers are framed structures. K.578.

790. Lloyd's "cross-roller" gear. Presented by the Quadrant Cycle Co., 1899.

This construction of toothed gearing was patented in 1897 by Messrs. W. and J. Lloyd and W. Priest, as a means of reducing the friction and wear of spur or bevel wheels when used for power transmission.

The arrangement shown represents this gearing as fitted to a bicycle, in place of the common sprocket wheels and pitch chain. Each of the four bevel wheels used consists of a disc, from the side of which project pins each carrying a roller of conoidal form. The other end of the pins is supported by a second disc, deeply notched, and the two sets of rollers when the wheels are in gear act as spur teeth; but owing to their being free to turn upon their axes, which are mutually at right angles, there is no sliding movement upon the faces of either set of rollers. K.575.

791. New Departure coaster hub. Presented by Messrs. Brown Brothers, Ltd., 1910 and 1911.

This is a specimen of the combined coaster or free-wheel cycle hub and back-pedalling brake, patented by the New Departure Bell Co., U.S.A., in 1898 and 1900.

The hub shell is enlarged to accommodate the operating mechanism and has a hollow brake drum formed at one end. At the other end is a driving sleeve carrying the chain ring, running between ball bearings on the spindle and hub shell, and having a triple thread of quick pitch formed on its outer cylindrical surface. In the middle of the hub is a loose clutch sleeve, having at one end an internal thread fitting the driving sleeve, while the other end is conical, inside and out. When the driving sleeve is rotated by the chain, the outer cone is drawn into engagement with a conical surface in the hub barrel, and so locks the chain ring and wheel together; when, however, the pedals and chain ring are held stationary, the clutch sleeve is moved out of engagement with the hub, thus freeing the wheel, and its inner cone engages with a practically fixed brake cone, which also forms the ball-bearing cone for that end. Within the brake drum are arranged three separate expanding steel rings attached to a casing, which is prevented from rotating by a lever arm bearing against one of the chain stays. The rings are expanded against the drum by short levers acting between their free ends, the levers having projecting arms which are moved by three lugs on the brake cone when backward pressure is applied to the pedals. The clutch sleeve is prevented from turning with the driving sleeve by a key slot cut in it, which engages with a tongue on a light helical spring fitted loosely in the hub. The bearing balls are fitted with cages to facilitate assembling.

Besides the complete hub, its component parts are shown in various stages of their construction. K.613 and M.3836.

792. Free-wheel clutch. Presented by the Micrometer Engineering Co., Ltd., 1907.

This is a specimen of the springless free-wheel for cycles, patented by Mr. H. Jelley in 1899. It is arranged with a transparent cover so as to show the mechanism.

The clutch centre, which is screwed on to the hub of the wheel, is provided with ratchet teeth, and the inner circumference of the chain ring, which runs

upon ball bearings, is provided with a number of circular notches facing the ratchet teeth. The reverse arrangement is sometimes used, *i.e.*, with the ratchet teeth in the chain ring and the notches formed on the hub ring. In these notches, and projecting from them, loose crescent-shaped pawls are placed, which rock and allow the ratchet teeth to pass them when the wheel overruns the chain. When, however, the chain is driving the ratchet teeth depress the rear ends of the pawls, causing their front ends to project and engage with the adjacent teeth. Three of the six pawls in this specimen are simultaneously engaged, and there is no possibility of the clutch slipping. K.598.

793. Sturmey-Archer change-speed gear. Made by the Three Speed Gear Syndicate, Ltd. Received 1906.

This is an arrangement for obtaining three changes in the ratio of the speed of the chain ring to that of the wheel. All the parts of the gear are arranged concentrically round the fixed spindle of the back wheel. A clutch with teeth on its edge and on its face is attached to the chain ring, and outside this, fitting tightly in the hub and always turning with the wheel, is a ring which forms an annular ratchet wheel. Further along the spindle to the left there is a comparatively heavy ring, the right-hand portion of which is of smaller diameter than the rest and rotates inside the ratchet ring; it carries two outside pawls, which engage with the ratchet ring when on the middle and high gear, and two inside pawls which engage with the edge of the clutch when on the low and middle gear. The left-hand portion of the heavy ring contains an annular spur wheel of fine pitch, in gear with which are four pinions carried round inside the ring, engaging also with a barrel pinion which is keyed fast on the spindle. The axes of the pinions are carried on an inner ring which is fixed to a ratchet wheel on the left of the heavy ring, and is free to rotate inside the latter. The ratchet wheel, inner ring, and heavy ring are all moved axially as one piece by a sliding flanged collar which is fixed to a long pin inside the spindle, and can be moved by the pull of a chain which passes through the nut on the right-hand side of the spindle, and is operated through a wire, either from a lever and quadrant on the top bar or from a lever and notched ring on the handle-bar. When on the low gear the wire is slack, and the collar is held by a spring in the extreme left position; the inside pawls on the right engage with the edge teeth of the clutch, thus turning the heavy ring, and, through the epicyclic train of wheels formed by the annular spur wheel, the four pinions and the long barrel pinion, moving the ratchet wheel on the left which engages with two pawls fixed inside the hub, and so drives the back wheel of the bicycle. The long pinion has 20 teeth and the annular wheel 64, which gives a reduced motion of 23·6 per cent. compared with the middle speed.

When the wire is tightened so as to use the middle gear, the left ratchet wheel moves to the right, putting the pawls on the hub out of gear; the inside pawls on the right of the heavy ring remain in gear with the clutch, and the outside pawls now come into gear with the inside ratchet ring; thus the wheel is driven directly without the epicyclic train affecting its motion, but the latter continues to revolve.

Tightening the wire and chain still further, the high gear is brought into use, and the projecting axes of the four pinions, which are shaped like pawls, are brought into gear with the face of the clutch; the inner pawls of the heavy ring are now moved beyond the teeth on the edge of the clutch and are disengaged, but the outer pawls still engage with the annular ratchet wheel on the right. The motion is now conveyed from the chain ring through the face of the clutch to the loose ring carrying the four pinions which, revolving round the long fixed pinion, drive the heavy ring, and with it the hub, 31·25 per cent. faster than the chain ring.

The chain ring has 18 teeth. With a sprocket of 56 teeth and a 28 in. wheel, the low gear would correspond with a 66·3 in., the middle gear with an 87·1 in., and the high gear with a 114·3 in. wheel. The wheel is free at each speed. K.593.

794. Pedersen change-speed gear. Made by the Dursley-Pedersen Cycle Co. Received 1906.

This is a partly sectioned specimen of the three-speed cycle hub patented by Mr. M. Pedersen in 1902. The gear is of the epicyclic type, runs solid on the normal speed, gives a higher speed 50 per cent. above and a lower speed 33·3 per cent. below the normal. A free-wheel is obtained at each speed and ball bearings are fitted throughout.

The fixed central spindle is hollow at one end and a toothed wheel, which is prevented from rotating by feathers on the spindle, slides upon its enlarged central portion. This wheel is moved endwise against the action of a spring by a bar, fitted in a slot cut in the spindle, and attached to a chain passing through the hollow end. The hub shell is in one piece having a parallel portion, at the ends of which the spoke flanges are brazed, and an extension of smaller diameter at the chain ring end. The shell has a ball cup at each end, and the corresponding cones, with the balls attached, are secured to the spindle. The left-hand cone is screwed on a coarse buttress thread and is milled on its outer face, so that when the outer nut is tightened up it will securely fasten the spindle to the fork and so resist the tendency of the sliding wheel to rotate it. On the hub extension is mounted, on a ball bearing, a spur wheel to the outer side of which is secured the driving chain ring; this ring locks the outer cone of the bearing by pressing against a flange on it. At the inner side of the spur wheel a loose clutch ring is placed, provided with ratchet teeth on both sides, the teeth on the outer side being considerably larger than those on the inner side. The driving force is received on the sloping backs of the large teeth from similar teeth formed within the spur wheel, so that on the normal gear the chain drive forces the small teeth of the clutch ring to engage with corresponding teeth cut on the hub shell. When free-wheeling, the hub teeth over-run those of the clutch ring, the large teeth of the latter having sufficient clearance to allow it to move endwise against the action of a light spring. A loose ring, provided with three studs projecting through slots into the interior of the hub, is fitted inside the clutch ring; the sliding wheel pushes this back and disengages the clutch when the low gear is required. The hub flanges are extended at one point to form the supports of a counter-shaft which carries a double spur wheel in the middle and a pinion at one end gearing with the chain ring toothed wheel; the double wheel is connected with the shaft through a clutch ring of similar form to the main one. Parallel with this shaft is placed an intermediate spur wheel, mounted on a spindle screwed into a boss on the right hand flange, and gearing with the smaller portion of the double wheel. For the normal gear the sliding pinion is in mid position and clear of the other wheels; the chain ring then drives the hub directly through the main clutch. For the high speed the sliding pinion is moved by the spring to the left, when it gears with the larger part of the double wheel on the countershaft, causing the hub to revolve faster than the chain ring while the hub ratchet teeth overrun those of the clutch ring. For the low speed the pinion is pulled to the right, when it disengages the clutch, and gears with the countershaft through the intermediate wheel, causing the hub to revolve slower than the chain ring. The teeth of the chain ring spur wheel, being only required to drive in one direction, are cut into the non-symmetrical and stronger form in which the driving faces are of the usual shape, but the backs, being less inclined to the pitch circle, leave more metal at the roots. The gearing is covered by closely fitting casings. The chain which actuates the sliding pinion passes out of the axle end and is connected by a wire cable with a lever working in a notched quadrant, attached either to the top bar of the frame or to the handle-bar. The weight of the complete hub is 2·35 lb. K.595.

795. Eadie two-speed gear. Lent by the Birmingham Small Arms Co., Ltd., 1910.

The first two-speed gear for bicycles, incorporated in the driving wheel hub, was patented by Mr. W. Reilly and others in 1896 and 1899. The one

shown, while being of the same general design, is constructed in the manner patented by Mr. A. Eadie in 1903.

The gearing is of the epicyclic or "Crypto" type. The wheel hub is enlarged at one end and carries the four fixed spindles upon which the planet pinions revolve. An outer internally-toothed ring gears with the pinions, runs on ball-bearings on the spindle and hub, and has screwed on to it a free wheel chain ring. The central sun pinion slides longitudinally on the spindle and is always in gear with the planet pinions; its inner end forms one member of a dog clutch, which engages with a similar member fixed to the spindle, when in its inward position, while its outer end engages with teeth formed in the inner portion of the toothed ring, when in its outward position. When the pinion is outward the gear revolves solidly, giving the normal high gear, while when it is in the inward position the hub rotates at a lower speed than the chain ring, the reduction being 21·4 per cent.

The spindle is hollow and bell-mouthed at the end, and a rod within it, forced inward by a spring, is connected with the sliding pinion by a pin passing through a slot. A piece of chain passing round the bell-mouth connects this rod with a wire which passes over a pulley to a lever fitted on the top tube; the lever can be held in either of two positions, and the wire connection has a screw adjustment for length. K.612.

796. Friction brake. Made by the Chamberlain Patent Brake Syndicate. Received 1906.

This brake, which is shown applied to the front hub of a cycle, was patented in 1903 by Messrs. W. & A. Chamberlain. The brake is combined with the hub, the shell of which is enlarged at one side and made of V-grooved section internally to take three segments, which fill the circumference, with the exception of a space which is occupied by the boss of a lever with a flat on it. This lever is centred on a pin in the end cover of the hub, which is held to one of the forks by a clip arm, and when slightly rotated expands the segments into the groove. When released a 3-arm spring-piece engaging in slots in the segments draws them back towards the centre.

The brake is applied from the handle-bar by a hand lever and adjustable rod. K.592.

797. Torpedo coaster hub. Presented by the Tormo Manufacturing Co., 1914.

This is an example in section of the combined free wheel cycle hub and back-pedalling brake patented in 1903, 1908 and 1910 by Mr. E. Sachs.

The free wheel is given by a roller clutch acting against the inside of the hub shell next the chain wheel. The back-pedalling brake is a split spring steel drum with a phosphor-bronze sleeve of large area grooved to retain lubricant. This drum is situated inside the hub shell in the centre of its width so that it has no tendency to twist the wheel. The drum is coned internally at both ends. A brake cone adjusted on the screwed spindle and connected to a brake arm fits in one end and has a snug to prevent rotation of the drum. In the other end fits a brake actuator which gets the end motion sufficient to expand the drum against the hub shell from an inclined face claw clutch actuated by the driving sleeve to which the chain wheel is screwed, when the latter is pedalled backward. To prevent the brake actuator simply rotating, it is made in the form of a spring roller clutch to engage with corrugations on the inside of the drum. Inv. 1914–7.

798. Three-speed bicycle hub. Lent by the Armstrong Triplex Three Speed Co., Ltd., 1911.

This is a sectioned example of the three-speed gear patented by Mr. A. H. Reilly in 1906 and 1908. In it two equal and separate epicyclic trains are used, one for the high speed and the other for the low, while both sets of four

planet pinions are mounted on one carrier which runs in a roller bearing on the spindle. The low-gear train has its outer internally-toothed ring fixed to the chain wheel, and the high-gear train has a loose outer ring running on the planet-pinion carrier and provided with pawls for a ratchet clutch. Other similar pawls are mounted on a ring fixed to the end of the pinion carrier close beside the first, and the hub shell has fitted within it, at one end, a ring with ratchet teeth wide enough to serve for both sets of pawls. The two central or sun pinions always remain in gear with their planet pinions, but slide independently endwise on the hollow spindle, being moved by an internal rod which bears against a bush having a cross pin projecting through a slot in the spindle. Helical springs tend to push the pinions towards the centre and out of engagement with two internally-toothed clutch members fixed to the spindle, one at each end. Another spring in the hollow spindle holds the actuating rod in its outward position and is strong enough to overcome the spring behind the low-gear sun pinion, so that it is engaged with its clutch and thus fixed to the shaft. In this position of the gear the chain wheel carries with it the outer member of the train, causing the pinion carrier to rotate at a speed 24 per cent. below that of the chain wheel and to drive the hub through the ratchet clutch; the other sun pinion being quite free, its train is inoperative. When the rod is pushed into its mid position, the low-gear pinion is disengaged from the spindle and brought into gear with a plate attached to the pinion carrier; this locks the pinions and driving ring together so that the gear revolves as a whole, giving the normal speed. A further movement of the rod fixes the high-gear pinion to the spindle, and the chain wheel drives the pinion carrier through its outer ring and locked pinions, so causing the outer ring of the second train to be driven at a speed 31 per cent. in excess of the speed of the chain ring, and driving the hub through its pawls; the hub meanwhile overruns the pawls on the pinion carrier, which is moving at a lower speed. The hub ratchet and pawls provide a free wheel on all speeds.

The operating rod has an indicator wire projecting from the other end of the spindle and is pushed in by one arm of a bellcrank lever, mounted on a bracket screwed on to the end of the spindle, the other arm of which is attached to a wire leading to the controlling lever fitted on the handle-bar or the top tube of the frame. M.3953.

799. Three-speed coaster hub. Lent by the Armstrong Triplex Three Speed Co., Ltd., 1911.

This is a sectioned example of the Armstrong three-speed bicycle hub, in which is incorporated a back-pedalling expanding-ring brake of the form patented by Mr. A. H. Reilly in 1907.

The three-speed gear is identical with No. 798 adjacent, except that the planet-pinion carrier is extended, and is provided at the end with a pawl for actuating the brake. This pawl operates in the opposite direction to the hub-driving pawls, and it engages with ratchet teeth inside a surrounding ring, which forms part of a disc carrying the end ball-bearing. The disc has a slot in it that fits over a pin projecting from the longer arm of a lever, the shorter arm of which bears against the free end of a steel ring so as to expand it inside a drum screwed into the end of the hub shell. The lever and expanding ring are mounted on an end plate having a long arm, which is secured to one of the chain stays of the frame. The brake is brought into action on all speeds and in any position of the pedals by a backward pressure on them, but special provision has to be made to enable the bicycle to be wheeled backwards. The cylindrical end of the pinion carrier to which the brake pawl is fitted, is surrounded by a loose ring, having a slot in it through which the pawl projects. A slight relative movement of the ring, given by the frictional contact of a spring engaging with notches in the ring and pressing against the hub shell, withdraws the pawl out of engagement with its ratchet ring. The hub-driving ratchet ring is not rigidly fixed to the shell, but is allowed to have a slight relative rotation between stops, and is held in its backward

position by a light spring; when the chain wheel is being driven, the hub ratchet ring is pushed forward by the amount necessary to put the brake pawl out of action, and the same condition is maintained when the driving wheel is rotated backwards against the resistance of the chain and pedals. On back-pedalling, however, the hub ratchet ring first moves back and releases the brake pawl, so that further motion applies the brake. The free wheeling is not interfered with except by the slight friction of the extra pawl and ratchet. M.3954.

800. Three-speed motor cycle hub. Lent by the Armstrong Triplex Three Speed Co., Ltd., 1911.

This is a sectioned example of the three-speed motor cycle hub, with which is incorporated a friction clutch that allows the engine to run independently of the driving wheel when necessary; it was patented by Mr. A. H. Reilly in 1909.

The change-speed gear is similar to No. 798, but is slightly modified so that the drive on all three speeds is transmitted through the outer toothed ring of the high-speed train, which has a cylindrical extension of smaller diameter, forming the driving member of a multiple plate clutch. The outer member of the low-speed train is fixed to the belt driving pulley, and the eight planet pinions of the two trains are mounted on one carrier. On the normal speed, both sun pinions are engaged with the planet pinion carrier, the whole gear thus revolving together. For the low gear one sun pinion is fixed to the spindle and the other to the carrier, so that the whole of the high-speed train revolves together, with the carrier, at a slower speed than the driving pulley; for the high gear the positions of the sun pinions are reversed, so that the drive is transmitted through the locked low-speed train and pinion carrier, causing the second outer ring and clutch member to revolve more rapidly than the driving pulley.

The driving clutch barrel has four longitudinal slots cut through it, and on it are loosely fitted seven steel plates or discs, which are prevented from turning by two flats formed on the barrel; these plates alternate with an equal number of copper plates which are clear of the barrel, but have outside lugs that engage with projections inside the hub shell. The plates are pressed together by a number of helical springs mounted at one end of the barrel, and acting on a loose ring, while the spring thrust is taken by another ring screwed on to the other end of the barrel. The clutch is disengaged by an internal sliding sleeve having four projections on it, which fit the slots in the barrel and bear against the loose ring, so as to compress the springs and relieve their pressure on the plates. The sleeve is moved by a ball-bearing collar acted upon by a pin projecting through a slot in the hollow spindle; this pin is fixed in a bush moved by a rod, which is acted upon by one arm of a bell-crank lever mounted on the end of the spindle. The other arm of the bell-crank is connected with a pedal, which remains fixed in either position. A chain ring, with free-wheel clutch, is fitted to the end of the hub shell opposite to the driving pulley for starting the engine by the pedals. The engine can thus be started with the clutch engaged and the driving wheel off the ground; if the clutch is then disengaged and the wheel lowered, the cycle can be started smoothly by the gradual re-engagement of the clutch. M.3955.

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801. Dunlop pneumatic tire, 1888. Lent by the Dunlop Pneumatic Tyre Co., Ltd., 1910.

This is a specimen of the pneumatic tire for cycles, patented by Mr. J. B. Dunlop in 1888–89. The idea of an air-filled tire was not new (*see* No. 755), but it did not come into practical use until the advent of the safety bicycle, which, being a vehicle with small wheels that could not be fitted easily with any ordinary form of spring, was eminently suitable for its application. The elasticity of the pneumatic tire renders it capable of absorbing the vibration

and shocks due to the roughness of the road, which would otherwise be transmitted to the vehicle and rider, thus giving greater comfort with reduced propulsive effort and increased speed. These advantages caused it rapidly to supersede the solid rubber tire, and subsequent improvements, in the direction of increased durability and less liability to puncture, have produced what is now practically a perfect cycle tire.

The tire shown has an inner tube of rubber provided with an inlet tube and a non-return valve; this is enclosed by an outer cover consisting of a canvas strip, coated with rubber solution, the edges of which overlap one another and are wrapped round, and cemented to, the wheel rim. The edges of the canvas would be slit to pass the spokes of the wheel, but the specimen does not show this. A thin rubber wearing band is solutioned to the tread. The tire is not detachable. M.3733.

802. Bartlett-Clincher cycle tire and rim. Presented by the North British Rubber Co., Ltd., 1910.

This is a specimen, as originally made, of the pneumatic tire patented by Mr. W. E. Bartlett in 1890. The cover is formed with thickened canvas edges of dovetail shape, and fits into a channel-shaped rim, the sides of which are bent inwards at an angle of about 65 deg. The tire is held in position by the inflation of the air tube, but in this form it was liable to come off when accidentally deflated; the thickened edge has, however, since been developed into the beaded edge, which hooks under the curled edge of the rim, and this form is now universally used for motor car tires (*see* No. 756). The tire shown is 2·5 in. wide by 36 in. diam. on tread. M.3808.

803. Pneumatic cycle tires. Lent by the Dunlop Pneumatic Tyre Co., Ltd., 1910.

The first pneumatic bicycle tires, made by Mr. J. B. Dunlop in 1888-89 (*see* No. 755), were not detachable; but efforts were soon directed towards the manufacture of tires which would permit the easy and rapid removal of the air tube for repairs, while at the same time preserving a secure attachment of the cover to the rim of the wheel. Several devices were tried, but only two have survived. In one of these, patented by Mr. C. K. Welch, in 1890, the cover is held on by endless wires embedded in its edges, the wire rings being smaller in diameter than the outside of the rim, but larger than its smallest diameter, so that they cannot be removed unless the tire be deflated. In the other method, patented by Mr. W. E. Bartlett later in the same year, the edges of the cover are thickened and fit into recesses, formed by turning over the edges of the rim, where they are held by the inflation of the air tube. Another improvement was the use for the lining of the cover of a single thread fabric having its threads set diagonally so as to withstand better the driving stresses without distortion of the cover. This material, which consists of two layers of parallel threads crossing one another at an angle and embedded in a thin layer of rubber, was patented by Mr. J. F. Palmer in 1892.

Seven sections of Dunlop cycle tires are shown. They all have separate air tubes composed of a rubber strip bent round to form a tube, its edges being butted together and cemented, while the joint is strengthened by an internal cover strip which is placed opposite the tread of the tire. The tube is moulded to a circular form and is fitted with a non-return valve, the stem of which passes through the rim; it is enclosed in a cover of horseshoe section formed of layers of fabric covered outside with a coating of rubber, the whole being moulded and vulcanized together by special machinery patented by Mr. H. J. Doughty in 1896.

No. 1 is a roadster tire of the wired-on pattern. The cover fabric has, besides the main parallel diagonal threads, a few light interwoven cross threads; the edges of the fabric are wrapped round the wires and stitched

along. The rubber coating is thickened at the tread, where circumferential ridges are formed to obviate side slip, and it is also thickened slightly where it bears against the rim. A band of tape is laid inside the rim to prevent the air tube from being injured by the ends of the spokes.

No. 2 is a similar tire of the beaded-edge type. Rings of rubber of triangular section are incorporated in the edges of the fabric to form the beads that engage with the rim. These edges are extended inwards so as to meet and overlap inside the rim.

No. 3 is a wired-on road-racing tire. The fabric used is of finer texture than the preceding and has more cross threads. It is not coated entirely with rubber, but has only a rubber tread and two narrow strips where it bears against the rim.

No. 4 is a wired-on path-racing tire. The cover is made of a very fine fabric and has a smooth rubber band on the tread only.

No. 5 is a non-detachable sprint tire for use on cement tracks. The fabric of the cover is formed as a complete tube, enclosing the air tube, the edges being overlapped and sewn together, A band of woven canvas is cemented within on the inner side and a plain rubber band on the outside of the tread. The complete tire is cemented to the wheel rim.

No. 6 is a wired-on motor cycle tire; the cover is formed of four layers of ordinary fabric with a rubber coating, having a thick tread provided with circumferential ridges.

No. 7 is a beaded-edge tire for motor cycles. The cover lining is a double layer of a strong woven fabric with diagonal threads; a thick rubber coating is applied to this, and the tread is much thickened and provided with a circumferential ridge, supplemented by elongated rubber studs, for the prevention of side slip. M.3734–40.

804. Double-clinch motor cycle tire. Presented by the Coventry Rubber Co., 1912.

This form of pneumatic tire cover was patented by Mr. J. Jelley in 1912. In it the side walls are gradually thickened up with rubber towards the beaded edge, thus forming a buttress that rests on the edge of the rim and prevents the tire from rolling.

The edge of the rim is gripped between the bead and buttress, thus preventing the tire from creeping or water from entering the cover. A non-skid tread is formed by two circumferential square ridges, one on each side of the centre line. Wired-on tires are made with similar buttresses, and they enable the wires to be made of the correct size for easy removal, while preventing them from slipping down the shoulders of the rim. The tire is also made in ordinary bicycle sizes. M.4150.

805. Self-sealing air tube. Presented by the Self-Sealing Rubber Co., Ltd., 1910.

This is a specimen of the air tube for pneumatic tires patented by the makers in 1896. The tube is reinforced inside, opposite the tread, by a band of vulcanized rubber somewhat thicker than the tube itself; this band is highly compressed when applied and the compression is considerably augmented when the tire is inflated. If a puncture is made it immediately closes up and remains sealed, no repairs being necessary. M.3804.

806. Detachable air tube for cycle tires. Lent by the Rich Patent Detachable Air Tube Co., 1910.

This is a specimen of a detachable air tube patented by Mr. F. Rich in 1904 and 1906. The use of such a tube permits of its complete removal for repairs, or replacement by a spare tube, without removing the wheels from their forks.

The tube has open ends, each contracted and furnished with a thick rubber ring. One of the rings is turned inwards and the other end of the tube is passed through it and drawn back so that the two rings bear against one another and are securely held together by the air pressure when the tube is inflated. The joint is covered by a thin rubber sleeve attached to one end of the tube. The open ends of the tube permit free circulation of the enclosed air and enable patches to be placed on the inside; the valve is also seated on the inside of the tube. M.3805.

807. Stuart lock-joint detachable air tube. Presented by Messrs. Chas. Macintosh & Co., Ltd., 1911.

This is a detachable inner tube, for cycle tires, with a joint of the form patented by Mr. J. Lees in 1907. The tube has closed ends, so that there can be no possible leakage at the joint, and one end telescopes into the other, where it is secured by the air pressure. One end of the tube is closed by a round-ended thimble piece and the other by a similar internal thimble piece, the inner end of which is cemented to the tube at one side so that it cannot be withdrawn when the joint is parted. When the tube is inflated the free ends have a tendency to swell and so interlock with one another. M.3956.

LAND TRANSPORT.—II.

Tram and Railways, Including Signalling Appliances.

Permanent Way.—The provision of smooth wheel tracks which should both withstand wear and reduce the power required in haulage was to some extent practised by the Romans, who used stone blocks, but the modern development of the system dates back prior to 1600, when the laying of longitudinal timbers on the road was already practised in mining districts in connection with the coal industry. Wooden curbs were sometimes added to these timbers. These wooden ways wore irregularly and at first were patched with wood, but in 1767 facing plates of cast iron were substituted at Coalbrookdale, with a marked reduction in the wear and also in the tractive resistance experienced. The wheels used on these wooden railways were described in 1676 as four rowlets fitting the rails; they were probably small wooden wheels or rollers shaped so as to prevent them from running off the rails. In 1734, however, cast iron wheels with a single inner flange were in use near Bath, while similar wheels are recorded at Whitehaven in 1738, and at Newcastle in 1764. In 1776 a cast iron "plateway" was laid at Sheffield; this was of angle section, the raised flange of which prevented the wheels slipping off the narrow track provided. Although this plate way possessed the advantage of allowing the use of ordinary vehicles upon it, it was open to the serious objection that it caused the accumulation of dirt and stones where they were most prejudicial.

The invention of the narrow iron edge rail is due to William Jessop, who, in 1789, constructed a railway in Leicestershire on this system and subsequently introduced it into other localities. The rapid wear of both his rails and wheels, however, soon showed the necessity for a wider bearing surface than he originally allowed. These rails were, moreover, provided with cast iron feet by which they were secured to the sleepers, but it was found that these feet were frequently broken off, thus rendering the rail useless; this defect was ultimately overcome by the introduction of detached feet or "chairs," used first in 1797 in the Newcastle district.

Wrought iron, although expensive, had for many years been used as a wearing face for wooden rails, but it was not until 1805 that it was used by itself as a girder rail, and then it was of rectangular section. The more economical T-section was introduced by J. Birkinshaw in 1820, and much ingenuity was subsequently displayed in rolling the lower web to the "fish-bellied" outline which, although correct for the 3 ft. cast iron rails, was wrong for resisting the stresses in a continuous rail 12 to 18 ft. long with intermediate supports.

Parallel rails with a lower flange smaller than the head were introduced about 1830, and on the failure of the fish-bellied pattern, were used on the Liverpool and Manchester Railway in

1834. The double-headed rail was introduced by Joseph Locke in 1835, the intention being to reverse it when one head was seriously worn. This system, rendered necessary by the irregular wear of wrought iron rails, continued in use for about thirty years, although the under surface was injured where it rested on the chairs. The rails were afterwards rolled to the now common bullheaded section. The flat-footed or flanged rail was also introduced about 1830 and is extensively used in America and elsewhere, its great advantage being that it can be fixed directly to the sleepers without the use of chairs. The ends of the early rails were butted or lap-jointed together in special chairs, but in 1847 Mr. W. B. Adams introduced the fish-plate joint, now universal.

A great improvement in permanent way was the substitution of steel rails for those of iron, a change that commenced about 1870, and for which the Bessemer process is to be chiefly credited by its having so greatly increased the output and reduced the cost of steel. Wrought iron rails wear down at about twice the rate of steel ones, but owing to the wear of the steel being uniform, while the wrought iron, after a time, frequently becomes laminated so that it splits or bulges irregularly, it has been estimated that a steel rail may last as long as fifteen iron ones. The almost unlimited length that can be obtained in a steel rail is another advantage which it possesses over one of wrought iron; steel rails, frequently weighing 100 lb. per yd. are now rolled in lengths of from 33 ft. up to 60 ft.

The sleepers generally used with the early cast iron plate ways were blocks of stone, one under each chair, and in the first public railway lines the same material was used in cuttings and on consolidated ground while transverse wooden sleepers were used on embankments; with the gradual increase in speed, the rigidity of the stone blocks and the absence of gauge ties were found to be serious defects, so that transverse wooden sleepers were gradually substituted. Brunel, however, on his broad-gauge lines, used a wide flanged rail bolted to longitudinal wooden sleepers which were tied together at intervals, and this system is still used on bridges. Metal sleepers have been repeatedly tried with considerable success, and are used exclusively where the insect life of a locality is destructive to timber; they are also largely used on narrow-gauge lines.

Monorail railways, with a rigid rail supported on trestles, have been successfully worked, but the type has been mainly developed in the form of aerial ropeways and telpher lines; in all these the centre of gravity of the load is below the supporting rail. It has, however, been shown, by Brennan and others, that vehicles can be run and balanced gyrostatically on a single rail laid on the ground in the ordinary way, but this system has not yet come into practical use.

Before the days of the locomotive, mine trams had been hauled by stationary engines through the medium of ropes, and the same system was used on the steeper inclines of the first public railways. Subsequently other devices for transmitting power to the trains were suggested, a notable one being the

atmospheric system which was put into practice by Messrs. Clegg and Samuda in 1840–8; the only transmission system, however, which has proved itself practicable is the electrical one, which is now being extensively adopted both for suburban and main line traffic.

Street Tramways.—The word tramway was originally applied to the early rail and plate ways used in mines and for colliery wayleaves. Street tramways having the features of a railway are a much later invention, and were first developed in America in 1832. They were introduced into England in 1860, but the early lines were nearly all removed in a few years and the system was practically abandoned in this country till its revival in 1870, since when its growth has been continuous. As the resistance of a tramcar on the level is generally under 25 lb. per ton, the loads carried are much greater than with vehicles running on the road surface, but the proportionate increase in the resistance due to inclines and to the inertia at starting is greater, so that for many years mechanical traction was much more extensively attempted with tramcars than with ordinary vehicles. Engines worked by steam, compressed air, gas, or electric accumulators, have been tried, but of all mechanical power systems those of the cable and electrical transmission are alone in extensive use. The cable system, introduced in 1873, gives constant speed and utilises the weight of the cars on the down grades to assist those on the up, but the construction of the central slot rail and the conduit, together with the guide pulleys, are expensive, and the renewal of the wire rope is a serious expense. The electrical system is cheap in first cost, provided that overhead conducting wires are tolerated, and it is that now generally adopted in provincial towns and suburban districts. The electrical system, introduced about 1883, with the conductors in a conduit besides one of the rails or in the centre of the track, is one of those by which the overhead wire is avoided, but it is more expensive and has only been adopted in large cities.

Signalling Appliances.—Soon after the introduction of railways, signals from fixed posts were found to be necessary for instructing the drivers, and in 1834 the Liverpool and Manchester line adopted a form of signal that was extensively used, the signal and lamp being carried on a vertical shaft which could be rotated from below through 90 deg., so presenting two quite different appearances if seen from a straight line. The semaphore arm, introduced in 1841 by Sir C. H. Gregory, is the signal now almost universal, and from its certainty and general applicability is probably final.

The employment of the electric telegraph in working railway traffic was advocated and tried by Sir W. F. Cooke in 1837, while in 1842 he suggested the method of working now known as the block system, in which a definite distance was insured between the trains on the same line instead of a definite time only, a most important distinction that greatly increased the safety of railways. This system was first adopted on the Norfolk railway in 1844, but its use was not made compulsory until 1889. The

method of signalling by means of a code of beats on an electric bell was introduced by Mr. C. V. Walker in 1851.

In 1856 Mr. J. Saxby introduced a method of mechanically connecting the points and the signals at any junction in such a way that the dangerous combination of these two factors was rendered impossible, thus largely reducing the responsibility of the signalman. Further security was attained by the introduction, about 1870, of the lock and block system in which the outdoor signals are electrically interlocked with the indoor block instruments, so that the signalman is prevented mechanically from allowing a train to enter a section already occupied. Train actuated treadles and track circuits are now extensively used either to indicate the state of the line or to control instruments and signals.

Many attempts have been made to cause the train in passing to set the signal automatically, closing the line behind it, but occasional failure led to a few accidents that caused automatic signalling to be abandoned for many years; recently, however, considerable advances have been made in this direction by electric apparatus, the failure of which as with other signalling appliances only delays traffic, since the signal under gravity alone remains at danger. The mechanical labour involved in manipulating a large number of signals and points has led to the application of power to this work, water, compressed air, and electricity having all been considerably used, but such arrangements are only necessary in exceptional situations where the traffic is dense.

Permanent Way.

808. Model of early wooden railways. (Scale 1 : 12.) Made in the Museum, 1912.

Wooden railways for the conveyance of coal are known to have been in use by the end of the 16th century. In the Life of Lord Keeper North it is recorded that in 1676 "the manner of the carriage is by laying rails of timber from the colliery down to the river exactly straight and parallel, and bulky carts are made with four rowlets fitting these rails." They were generally laid on special tracks or wayleaves leading from the collieries to the riverside staithes. These railways at first consisted of rectangular oak rails, 4 or 5 in. wide and 6 ft. long, laid 3 or 4 ft. apart, and pegged down to similar cross sleepers placed 2 ft. apart and embedded in the ground. The wear of the rails afterwards led to the use of a double rail, the upper part of which could be replaced without disturbing the sleepers, and the latter could be entirely covered so as to protect them from damage by the horses' feet. Subsequently the durability was increased, and the tractive resistance reduced on inclines, by facing the running edge of the rails with a wrought iron bar about 2 in. wide and 0·5 in. thick. The model is arranged to show the three forms described. M.4033.

809. Model of cast iron railway, 1767. (Scale 1 : 12.) Made in the Museum, 1912.

The first recorded use of cast iron for rails was at Coalbrookdale Iron Works, where, in 1767, thick facing plates were laid down on the existing

wooden rails. The rails were cast in lengths of 5 ft., were 4 in. wide and 1·25 in. thick; they had three projecting lugs along their outer edges, by means of which they were fastened down. The longitudinal oak rails were 6 in. wide and laid to a gauge of 3 ft.; they were secured to cross sleepers placed 2 ft. apart. M.4034.

810. Cast iron edge rails. Presented by C. Stretton, Esq., 1892.

These rails were laid down by William Jessop in 1789 on a line between Nanpanton and the Loughborough Canal at Loughborough, the intention being eventually to form a connection with the Ashby coal field (*see* map). This is believed to have been the first instance of a narrow rail being used on its edge, and therefore marks a great advance upon the earlier wooden ways and plateways.

The rails were cast in 3 ft. lengths of a double flanged section, with a curved lower flange forming what has since been known as a "fish-bellied" rail. The lower flange at one end of a rail spreads out to form a foot, which by a central hole was spiked to a wooden cross sleeper. The top of this foot is so formed that the next length can be socketed into it, the spiked end of each rail securing the otherwise free end of the following rail. These rails are much reduced by wear, but probably weighed about 40 lb. per yard. They are, however, narrower and generally lighter than later examples of Jessop's make. M.2472.

811. Cast iron edge rails. Presented by H.G. the Duke of Rutland, 1892, and C. E. Stretton, Esq., 1900. Plate XI., No. 7.

These six rails, with the point and crossing, formed portions of a line laid from Belvoir Castle to the Grantham Canal in 1793, and still in use. The work was carried out with Jessop rails (*see* No. 810), made at Butterley. These were spiked down to plugs in stone blocks at a gauge of 4 ft. 4·5 in. The switch turns on a pin dropped into a hole in the foot of the stock rail, and is without any mechanical attachment for moving or fixing it. The line and the trucks are clearly shown in the attached photographs, and the route is marked in red on an adjacent ordnance map. M.2473.

812. Early plateway. Presented by the Midland Railway Co., 1893, and C. E. Stretton, Esq., 1900. Plate XI., No. 8.

These specimens are from the Ticknall tramway—a line 4·25 miles in length connected with the Ashby Canal, Leicestershire. This tramway was authorised in the Ashby Canal Act of 1794, and was constructed in 1799 by Benjamin Outram, following a route indicated on an adjacent ordnance map. It is still occasionally used.

The metals are of cast iron and of angle section, the raised flange being arranged on the inside of the track; the tread of the rails is 3·5 in. wide and 0·625 in. thick, while the flange is 2·75 in. high. The rails were laid to a gauge of 4·5 ft. over the flanges, and the wheels of the trucks were without flanges. The switch shown has a wrought iron tongue, provided with a stem which drops into a hole in the casting, but no mechanical device is provided for moving the tongue. One of the specimens shows the channel section rails used when the line crossed a highway. M.2539.

813. Early cast iron rails. Presented by Messrs. J. and C. Thompson, 1892.

These rails are stated to have been in use during the latter part of the 18th century on a mineral line in the north of England. Each rail is in the form of a rectangular bar with an elliptical stiffening rib below, while

the ends are thickened and provided with side flanges by which each length was directly secured to the wooden cross sleepers by four iron spikes; the abutting ends are, moreover, made concave and convex, possibly to give continuity round curves. The rails are in 3 ft. lengths, each weighing 35 lb., and the width of head is 2·25 in. M.2485.

814. Early cast iron edge rails. Presented by Messrs. J. and C. Thompson, 1892.

These were in use at the beginning of the nineteenth century and resemble No. 813, except in the method of fixing. Each rail is in the form of a rectangular bar with an elliptical rib below, while the ends are made deeper and widened outward on one side where they are provided with a through hole for a wooden plug or trenail; the ends are also notched to secure alignment. They were carried on stone blocks to which they were secured by trenails 1·4 in. diam. The rails are in 3 ft. lengths, each weighing 34 lb., and the width of head is 2·25 in. M.2486.

815. Toll sheet of the Surrey Iron Railway. Lent by Trovey Blackmore, Esq., 1876. Copy of the original plan of the line. Contributed by C. T. Davis, Esq., 1900. Portion of a plate rail. Lent by the London County Council, 1913. Stone sleepers. Presented by the Wandsworth Borough Council, 1906.

The plate ways, called the Surrey Iron Railway and the Croydon, Merstham, and Godstone Iron Railway, were the first lines of metals constructed for public use, the earlier tracks having been reserved for the exclusive use of their owners. They both formed portions of a scheme promoted in 1799 for improving the communication between London and Portsmouth by providing a horse tramway approximately parallel with the main road and open to the use of the public upon the payment of certain tolls.

The construction of the first portion—the Surrey Iron Railway—was sanctioned by Parliament in 1801 and, the work being at once commenced, it was finished in July, 1803, while, by 1805, the capital involved in the undertaking had reached 60,000*l*. William Jessop was the engineer, and the subscribers were chiefly the owners of mills and other property in the valley of the Wandle. The line commenced at a locked dock on the Thames at Wandsworth and followed up the course of the Wandle, which it twice crossed, to Croydon; there was, moreover, at Mitcham Common, a branch to Hackbridge, and several mills along the route had short connecting lines.

The rails were of cast iron in 38 in. lengths, 3·5 in. wide on the tread, and 0·75 in. thick, with an arched flange 2·5 in. high and 0·5 in. thick, projecting upward along one edge. These rails proving too weak a heavier section with an extra flange projecting downward from the other edge was adopted when repairing. The ends of adjacent rails were secured together on a stone block sleeper, 15 in. square and 8 in. deep, by a special spike driven into a wooden plug fixed in the block. The road was a double track to a gauge of about 4·7 ft. measured outside the flanges, which were arranged inside the treads; the maximum gradient was 1 : 120 and the high roads were crossed on the level, intermediate packing being laid in such situations to reduce the obstruction occasioned by the flanges.

The second portion of the line was known as the Croydon, Merstham, and Godstone Iron Railway, and its construction was authorised in 1803. It was intended to extend this line from Croydon to Reigate and to have a branch to Merstham and Godstone, but, owing to lack of capital, construction was stopped in 1805, when the line had reached Merstham limestone quarries, a distance of 8·75 miles. Starting from the Croydon end of the Surrey Iron Railway the line ran south over a course closely followed by the present Brighton Road; it was carried on an embankment on the west side of the road, then crossed by an arch to the east side and reached Merstham

through a cutting. Portions of the embankments and cuttings still remain, as also do three bridges over the cutting near Chipstead, but much of the route is now covered by the high road and by the Brighton Railway.

On both lines the traction was done by horses and it was considered that, at 2·5 miles per hour, one horse could draw a total load of 9,000 lb. and that the resistance was 37 lb. per ton. The wagons were 8 ft. long, 5 ft. wide, and 2 ft. deep ; each weighed about one ton and carried a load of 3·25 tons. The wheels were of cast iron and flangeless, 32 in. diam. by 1·5 in. face, and revolved on fixed axles 2·375 in. diam.

Neither of the undertakings was, however, financially successful, and in 1837 the portion of the line between Croydon and Merstham was purchased by the London and Brighton Railway Co., which in 1846 acquired the remainder, the present line from Croydon to Wimbledon now following part of this route. Both routes are shown on an adjacent ordnance map. Some specimens of the stone sleepers, unearthed at Wandsworth in 1906, are shown near. The views at Wandsworth and Chipstead are taken from *The Engineer*, January, 1900. M.2754, M.3452 and M.4201.

816. Wrought iron rail (1808). Presented by Messrs. J. and C. Thompson, 1902.

This is a specimen of the earliest form of wrought iron rail, and it was in use on a railway at Tindale Fell in 1808. The rail was simply a square bar, secured to stone blocks by iron spikes, which were driven through the rail into wooden plugs inserted in holes in the stone. It was originally 1·5 in. sq., and in 12 ft. lengths, supported at intervals of 3 ft.; it now weighs 17 lb. per yard. M.2487.

817. Plate rails. Presented by Captain E. A. Blackett, R.N., 1862.

These cast iron rails are from the wagon-way at Wylam, upon which the early locomotive "Puffing Billy" (*see* No. 188) worked in hauling coal trucks. The track was originally laid with wooden rails which, in 1808, were displaced by plate rails of the form shown; these remained in use till 1830, when the cast iron edge rails now retained under the engine were substituted.

This pattern of plate rail is similar to the earlier example No. 812, but is strengthened by the addition of a lower segmental flange, 2·75 in. deep at the middle. The rail is 3·5 in. wide on the tread, and is broadened out to 5 in. at each end where it rested on the sleepers, to which it was secured by a spike fitting the notches in the ends of adjacent rails. Each rail weighs 45 lb. and is a yard in length. M.339.

818. Blenkinsop rails and driving wheel. Lent by the Institution of Mechanical Engineers, 1890, and Messrs. John Spencer & Sons, 1893.

The specimens comprise an original rack rail, together with two similar rails, three chairs, and a driving wheel, cast at the Tyne Iron Works from what are believed to be the original patterns, made when equipping the rack line that connected the collieries of Kenton and Coxlodge with the Tyne, which was laid down in 1813 under the patent of John Blenkinsop, of Leeds. These rack rails enabled light engines to haul heavy trains up gradients which the smooth-wheeled locomotives of Trevithick could not have surmounted. The same arrangement is now generally adopted for mountain railways, except that the rack is now an independent structure midway between the two rails. The Kenton and Coxlodge Railway did not remain long in use, owing to the engine tearing up the rails, but the similar line at Leeds (*see* No. 186) worked successfully from 1812 till about 1835.

The original rail is of the cast iron fish-bellied pattern, but is provided on one side with semi-circular lugs, or teeth, into which the driving spur wheel

of the locomotive engaged. The rail is 3·4 ft. long, with seven teeth about 6 in. pitch by 2·25 in. face, and weighs 50 lb. Its chairs weigh 12 lb. each, and are formed with projections to fit under the end teeth of adjacent rails, so as to prevent longitudinal movement. The rails were secured sideways by wooden keys.

The other rails shown are in 3 ft. lengths, weighing 61 lb. each, and their chairs weigh 30 lb. each. The driving wheel is 38 in. pitch diam., and has twenty teeth 6 in. pitch. M.2325 and M.2529.

819. Early rolled rail. Presented by C. E. and C. Stretton, Esqs., 1903.

This example of a single-headed rail is a development of a form patented by J. Birkinshaw in 1820, there being better provision for securing it in the chairs.

The head is 1·4 in. wide, and the web, which is 2 in. deep, has a tapered bottom edge by which the rail is held down into its chair by the securing key. The rail weighs 15·5 lb. per yd., and the chair, which is probably later, weighs 5 lb. M.3307.

820. Early single-headed rail. Presented by C. E. Stretton, Esq., 1892.

This is a wrought iron parallel rail from Cole Orton, Leicestershire, where it formed part of a line laid along the bed of what had been the Charnwood Forest Canal (*see* map); the line, however, was never used, and in 1832 some of the rails were taken up and re-laid on the Cole Orton Railway.

The rails were rolled to a T-section with a continuous groove along one side of the web, and were secured in chairs by wrought iron keys which fitted into this groove and into corresponding grooves in the chair jaws. The chairs rested on stone blocks to which they were attached by iron spikes driven into wooden plugs. The rail is 15 ft. long, has a head 1·75 in. wide, and now weighs 25 lb. per yard; the chairs, which were made in 1832, weigh 16·5 lb. each and were spaced 3 ft. apart. M.2477.

821. Fish-bellied rail (1825). Presented by Messrs. J. and C. Thompson, 1892.

This early wrought iron rail is similar to those used on part of the Stockton and Darlington Railway in 1825, and this specimen may be from that line.

The first wrought iron rails, which were in the form of square or rectangular bars, proved to be too narrow, whilst simply increasing their size rendered them too costly to compete with those of cast iron. In 1820, however, John Birkinshaw, the manager of the Bedlington Iron Works, patented an improved construction of rolled prismatic rail, in which the metal was disposed in the form of a wide head and a narrow web, thus obtaining increased bearing and strength with the same amount of material. At the suggestion of John Buddle, the web was afterwards made of elliptical or fish-belly form so as to give greater depth of girder towards the centre of the spans; this was accomplished by using for the first pass a bottom roll having a groove of varying depth, and then completing the rolling by passing the rail flatwise between ordinary rolls.

The rail was rolled in 15 ft. lengths, had square ends, and was fastened by through pins to the chairs, which were secured by wooden pegs to stone blocks, placed 3 ft. apart. The head is 2·25 in. wide, and the rail now weighs 25 lb. per yard; the chairs weigh 6 lb. each. M.2489.

822. Fish-bellied rail. Lent by the Patent Nut and Bolt Co., 1889.

This rail is similar to No. 821 but heavier, and is believed to have been used on the Bolton and Leigh Railway in 1827. It was secured to the chairs

by transverse pins through the web, but the inefficiency of the method is shown by the hollows worn under the rail head by the hammering that resulted from the rail not remaining in contact with the tops of the chair jaws. The rail now weighs 28·5 lb. per yard, and the width of the head is 2·25 in. M.2266.

823. Rail from Shutt End (1829). Presented by W. O. Foster, Esq., 1884.

The Shutt End Railway in Staffordshire was a mineral line, extending from a colliery near Kingswinford to a basin on the Staffordshire and Worcestershire Canal, a distance of 3·12 miles; it was opened on June 2nd, 1829, by the locomotive "Agenoria" (*see* No. 192).

The rail is of the wrought iron fish-bellied type carried in chairs, the jaws of which support the under surface of the rail head; but instead of being held in the chairs by the transverse pins, then usual, the lower edge of the rail is provided on one side with a projecting ledge which fits into a corresponding recess in the jaw of the chair, while a key in a recess in the other jaw completes the fastening. At the joints the two adjacent rail ends were keyed together into a single chair.

The rail was rolled in lengths of 15 and 18 ft. forming 5 and 6 spans respectively, and weighed about 33 lb. per yard; it now weighs 29 lb. per yard and the chairs 7 lb. each. M.2474.

824. Views on the Liverpool and Manchester Railway. Presented by Clement E. and C. Stretton, Esqs., 1900.

This is a series of hand-coloured aquatints, drawn by T. T. Bury, and published by R. Ackermann, with descriptive letterpress, in 1831.

A tramroad or railway between Liverpool and Manchester had been proposed and a route surveyed for it in 1797 by W. Jessop, and in a modified form in the following year by B. Outram. A more direct route was adopted in a scheme prepared in 1822, and embodied in an unsuccessful application made to Parliament in 1825. The opening of the Stockton and Darlington Railway, however, caused the project to be revived, and an Act (a copy of which is shown in an adjoining case) authorising the construction of the line was obtained in 1826. George Stephenson, who had laid out the Stockton and Darlington Railway, was the engineer, and the line, which was much more direct than those previously proposed and only 31 miles in length, was opened for public traffic on September 16th, 1830. In 1845 it was amalgamated with the Grand Junction Railway, and these in the following year became part of the London and North Western system. The line was double throughout with wrought iron rails in 15 ft. lengths (*see* those under the "Rocket," Nos. 193 and 194), 13 miles of which rested on sleepers of oak or larch and 18 miles on stone blocks, the latter being used in cuttings. The gauge was 4 ft. 8·5 in. and the ruling gradient 1 in 89, the steep inclines into Liverpool being worked by stationary winding engines at Edge Hill.

At Liverpool there were three stations—one at Queen's Dock, which has been absorbed by the present Wapping goods station, another at Crown Street, now also a goods station, while the third has developed into the present Lime Street station. From these stations the lines proceeded through three tunnels to Edge Hill, where they joined; thence the railway proceeded to Manchester, where it terminated at the present Liverpool Road goods station, which served also as the passenger station till the line was extended to the Exchange.

The total number of bridges on the line was 63, of which 33 were of brick or stone, 19 of wood and masonry, and 11 of wood alone. M.3090.

825. Rail and chairs (1829–33). Presented by C. E. Stretton, Esq., 1894.

These formed portions of the main line of the Liverpool and Manchester Railway. The early locomotives "Rocket" and "Sans Pareil," now in the

Central Hall, stand on similar metals from the same line. The rails are of wrought iron, of the fish-bellied type, secured to the chairs by iron wedges and held down by a side rib.

The chairs differ in size, and vary in weight from 15 to 17 lb. each, the lighter ones being the earlier, but those for use on wooden sleepers have a larger base area than those for stone blocks; each chair was secured to its sleeper by two iron spikes. In 1833 a new pattern chair was introduced in which the keys were inside and there were specially wide joint chairs, two of which are shown, weighing 24 and 31 lb. respectively.

The sleepers used on embankments were half-round wooden cross ties 9 ft. long, while in cuttings the chairs were carried on stone blocks 20 in. sq. by 10 in. deep to which they were secured by spikes driven into wooden plugs forced into holes in the blocks. In the Olive Mount cutting the chairs were originally spiked directly to the rock bottom, but owing to the breakage of rails and chairs caused by the excessive rigidity, wooden sleepers were afterwards interposed. The fish-bellied rails, however, continued to break near the chairs and they were soon abandoned, the change to parallel rails weighing 50 lb. per yard being in progress in 1834.

The rail shown is 15 ft. long covering five spans of 3 ft.; it is 2·25 in. wide, 2·5 in. deep at the chairs, and 3·5 in. deep at mid-span. It originally weighed 35 lb. but now weighs 31 lb. per yard. M.2475.

826. Fish-bellied rails. Presented by Messrs. J. and C. Thompson, 1892.

These are of wrought iron, with the joints made at the chairs.

The first rail is of symmetrical section and was fixed in each chair by an iron key so arranged as to hold it down as well as to secure it laterally. The joints were made in the chairs by such keying, but the ends of adjacent rails were also rebated off so as to form the half-lap joint patented by Messrs. Losh and Stephenson in 1816. By this arrangement the serious jolting that occurred when the wheels passed over the gap between the rail ends was greatly reduced, but the fastening did not entirely prevent difference of level between the rail ends. The rail now weighs 27 lb. per yard and the chairs 10 lb. each.

The second is a deep rail with half-lap joints, but is furnished at the under side of the web with rounded projections which fit into cavities in the chairs, after the manner patented by Mr. W. Losh in 1828. This arrangement was intended to secure uniform bearing, even should the stone blocks settle irregularly, and it was adopted on the Newcastle and Carlisle Railway. The rail is rolled with a pair of wide grooves along the web, and is secured by a key on each side fitting into corresponding grooves in the chairs; it now weighs 33·5 lb. per yard, and the chairs 13 lb. each.

The third rail is similar to the Liverpool and Manchester rail of 1829, but is carried on wide-based low chairs, probably to obtain increased stability. The rail now weighs 30·5 lb. per yard, and the chairs 11 lb. each. M.2490–2

827. Combined plate and rail. Presented by the Midland Railway Co., 1893.

This wrought iron rail is from the Cloud Hill tramway of the Ashby Canal Co., and was laid down in 1833 to replace the plate rails previously in use, so as to obviate a break of system at the junction with the Cole Orton Railway (*see* adjacent ordnance map). In 1874 they were taken up and used elsewhere.

The rail is a combined plate and edge rail, flat wheels running on the plate and flanged ones on the raised ledge. It was rolled in 15 ft. lengths, and now weighs 41 lb. per yard. The lengths were dovetailed together, and were fixed in chairs on stone blocks or wooden sleepers at 3 ft. centres, with a rail gauge of 4 ft. 8·5 in., and the plate portion inside. M.2539.

828. Early permanent way. Presented by D. Drummond, Esq., 1902.

These portions are from the Bodmin and Wadebridge Railway, a Cornish mineral line, about 15 miles long, and of standard gauge, built in 1834. Further particulars of the undertaking are given in connection with the views of its passenger carriages (*see* No 936).

The permanent way consisted of granite block sleepers about 20 in. sq. by 12 in. deep, spaced at 3 ft. centres, while at intervals there were transverse blocks 6 ft. long, which acted as ties; each sleeper carried a cast iron chair (now weighing 10 lb.) secured to it by spikes driven into holes that had been plugged with wood. The rails are of wrought iron and of a uniform depth of 3·5 in., while the shape of the section approaches the present bull-headed form, the head being 2 in. wide and the foot 1 in., while the web is 0·5 in. thick; these rails weighed 42 (now 32) lb. per yard, and were connected by a half-lap joint made in a chair. M.3252.

829. Early wrought iron rail. Presented by Messrs. J. and C. Thompson, 1892.

This example of a parallel rail with a small lower flange was designed in 1835 by Mr. Daglish, who was awarded a premium for it by the London and Birmingham Railway Co. The chairs, which were carried on stone blocks, closely fitted the web of the rail, and were threaded on from the end; there were, however, spaces left above the lower flange for the reception of a pair of keys by which it was secured. The rail now weighs 28 lb. per yard and the chairs 10 lb. each. M.2488.

830. Views on the London and Birmingham Railway. Presented by C. E. and C. Stretton, Esqs., and John Hyde, Esq., 1900.

This is a series of lithographs drawn by Mr. J. C. Bourne while the line was under construction, and published with descriptive letterpress in 1838–9.

A railway between London and Birmingham had been projected as early as 1824; but, through opposition and the introduction of alternative schemes, it was not until 1833 that the Act authorising its construction was obtained, while the extension from the original terminus in Hampstead Road to Euston Square was only sanctioned in 1835. Part of the line was opened in 1837, and the whole 112·5 miles on September 17th, 1838. In 1846 the line was amalgamated with the Grand Junction and the Birmingham and Manchester Railways, the united systems becoming the London and North Western Railway.

A double line of standard (4 ft. 8·5 in.) gauge was provided for, and a ruling gradient of 1 in 330 adopted which, together with curves of not less than 27 chains radius, necessitated very heavy earthworks, so that the total cost of the undertaking with its equipment exceeded 50,000*l.* per mile.

The adjacent coloured aquatints form part of a series of views of the finished undertaking drawn by T. T. Bury and published by Ackermann & Co. in 1837. M.3091–2.

831. Single-headed girder rail (1838). Presented by C. E. Stretton, Esqs., 1892.

The uniform T-section rail was first rolled in 1820 by Birkinshaw, but was reintroduced by George Stephenson about 15 years later on his abandoning the elliptical pattern, after experience had shown its unsuitability; his reason for preferring the T to the double-headed section, advocated by Locke, was that he anticipated the wear of the lower head of a reversible rail, where resting in the chairs would render inversion impracticable.

The specimens shown were laid down in 1838 at Hampton-in-Arden, on the Birmingham and Derby Junction line, which was opened in 1839 and now exists as a portion of the Midland system. The deep parallel web of the rail is provided with a longitudinal groove for keying, and the joints were made by lapping, without, however, cutting the webs. The rails were secured in the joint chairs by a small iron ball on each side wedged up by split cotters; in the joint chairs shown, however, which date from 1840, the rail ends are secured by through pins. The intermediate chairs are of two forms, in one of which the rail is held by a single ball and cotter, and in the other by a plain iron key.

The rails were rolled in 15 ft. lengths, weighing 56 lb. per yard, and the chairs were spiked to wooden cross sleepers placed 2·5 ft. apart. The intermediate chairs weigh 19 lb. each and those at the joints 28 lb.; the original joint chairs weighed 24 lb. each. M.2483.

832. Double-headed rail (1839). Presented by the Midland Railway Co., 1909.

This is a portion of the permanent way designed by Messrs. C. B. Vignoles and T. J. Woodhouse, and laid on a part of the Midland Counties Railway in 1838–9. The earliest parallel rails had a lower flange, smaller than the head, but the rapid wear and lamination that took place led to the introduction, in 1835, of the double-headed rail, which could be inverted when one head was seriously worn.

The rail was made especially deep, so that it could be used in chairs placed 5 ft. apart, but the increasing weight of the rolling-stock made it necessary to decrease the span a few years afterwards. The rail was secured by wooden keys in chairs, which were spiked to wooden cross sleepers or stone blocks. The joints were made by keying the adjacent rail ends together in a chair of greater width than the intermediate ones. The rail was rolled in 15 ft. lengths, and weighed 78 lb. per yard; it now weighs 72 lb. per yard. The intermediate chairs weighed 23·5 lb. and the joint chairs 28 lb. M.3603.

833. Parallel rail (1839). Presented by C. E. and C. Stretton, Esqs., 1904.

This is a portion of the permanent way designed by Messrs. Vignoles and Woodhouse, which was laid on the Midland Counties Railway between Syston and Leicester in 1839. The rail was rolled with a very wide upper flange but a narrow lower one, and was secured, by wooden keys, in chairs which were spiked down to wooden cross sleepers or stone blocks. The joint was made by keying the adjacent rail ends together in a chair of extra width.

The rails were in 15 ft. lengths, and had the head 2·75 in. wide; the specimen now weighs 51·5 lb. per yard. The chairs were placed 5 ft. apart, and the intermediate ones shown weigh 19 lb. each. M.3324.

834. Flat-footed rail (1840). Presented by C. E. Stretton, Esq., 1892.

This piece of rail and the two chairs formed part of the permanent way of the Birmingham and Gloucester Railway, opened in 1840, which was probably the first line to use chairs for securing flat-footed rails. Capt. W. S. Moorsom, the engineer to the company, on returning from America, wished to use flat-footed rails spiked to sleepers in the usual manner, but the Directors, considering this attachment insecure, insisted upon the addition of chairs into which the rails were fixed by wooden keys. In 1865 some of these rails were sold to the Groby Granite Company, by whom these specimens were used until their presentation to this Museum.

The rails were laid on longitudinal timbers in cuttings, with chairs 5 ft. apart and bearing plates midway between; on embankments above 5 ft. in height

half-round cross sleepers were used, spaced 2·5 ft. apart. The rails were in 15 ft. lengths, weighing 56 lb. per yard; the intermediate chair weighs 17 lb. and the wider joint chair 21·5 lb. M.2476.

835. Rail, joint, and chairs (1840). Presented by the Midland Railway Co., 1893.

This is a portion of the permanent way laid on the North Midland line between Derby and Leeds in 1840. The rail is of a reversible section and was jointed in the wide chair shown—the usual arrangement till the adoption of fish-plates, which were introduced by Mr. W. B. Adams in 1847. Wooden keys were employed to fix the rails, and the chairs were secured to transverse wooden sleepers by two wooden trenails. The rail in its present condition weighs 57 lb. per yard, the ordinary chairs 21·5 lb. each, and the joint chair 22 lb. M.2536–7.

836. Rail and chair (1842). Presented by C. E. and C. Stretton, Esqs., 1904.

This pattern of rail was used in 1842 on the Birmingham and Whitacre section, known as the Tame Valley line, of the Birmingham and Derby Junction Railway. It is a non-reversible rail, with a smaller lower flange for holding it down, the earlier single-headed rail used on the same railway (*see* No. 831) having proved deficient in this respect. The rail was secured in the chairs by wooden keys, and the joints were originally made by keying the adjacent rail ends in wider joint chairs, but these were afterwards replaced by fish-plates.

The rails were in 15 ft. lengths, of two sizes weighing 65 and 68 lb. per yard; this specimen is the heavier pattern and now weighs 64 lb. per yard. The sleepers were placed about 3 ft. apart; the intermediate chair shown weighs 24 lb. and the joint chairs weighed 30 lb. M.3333.

837. Parallel rail (1848). Presented by Messrs. J. and C. Thompson, 1892.

This rail, which was in use at Kirkhouse in 1848, is of the bull-headed variety, but has the lower bulb greatly reduced and the internal angles so filled in as to give the web a continuous curve, possibly to facilitate rolling. It was secured by wooden keys to chairs which were attached to stone block sleepers, placed 2·5 ft. apart between centres; the joints were square butts meeting in a wide chair and there keyed. The rail now weighs 46 lb. per yard, the intermediate chair weighs 19 lb. and the joint chair 25 lb. M.2493.

838. Saddle-back rail. Presented by the Midland Railway Co., 1909.

This type of rail, patented by Mr. W. H. Barlow in 1849, was designed to dispense with chairs and sleepers; it was used to some extent on the Midland Railway. The rail is of a saddle-shaped section, with very wide flanges, curving outwards and downwards, which rested directly upon the ballast. The rails were rolled in 20 ft. lengths, and these were connected by joint saddles riveted inside them. The gauge was preserved by angle-iron cross ties placed 10 ft. apart, but these were found insufficient to prevent the rails from rocking, so that they were subsequently replaced by ties of the same section as the rail, and also by triangular wooden ones. The first rails made were 13 in. wide, 5·75 in. high, and weighed 126 lb. per yard; these were found to be unnecessarily heavy, and a lighter section, like the specimen shown, which is 12 in wide, 4·8 in deep, and now weighs 92 lb. per yard, was subsequently used. M.3604.

839. Rail and chairs (1850). Presented by C. E. and C. Stretton, Esqs., 1903.

This is a specimen of the permanent way laid by Mr. W. H. Barlow on the Midland Railway in 1850. The rail is double-headed and had originally much-rounded faces; it was rolled in 20 ft. lengths and weighed 80 lb. per yard. The joints were made in chairs, while wooden keys secured the rails in chairs, which were each fastened to wooden cross sleepers by two spikes. Fish-plate joints were added in 1852–4. The rail now weighs 68·5 lb. per yard, and the chairs 26 lb. each. M.3304 and 3326.

840. Barlow's cast iron sleeper. Presented by the Midland Railway Co., 1893.

This formed a portion of the permanent way of the Leicester and Swannington Railway, near West Bridge, where it was laid down about 1850 and remained in use till 1893. The arrangement had, however, been long abandoned on important sections, as after a thorough trial it was found that with the increasing axle loads these sleepers frequently broke.

The sleeper, which was patented in 1849 by Mr. P. W. Barlow, consists of a long inverted trough of cast iron, closed at the ends, with two chairs cast on it and a socket into which is pinned a heavy wrought iron tie-rod. These sleepers were arranged longitudinally, and with their chairs weighed 160 lb. each. M.2538.

841. Compound rail (1851). Presented by W. B. Adams, Esq., 1858.

This is one of many forms of girder rail patented by Mr. Adams in 1851, 1854 and 1856. It is a single-headed rail and rolled with a deep web finishing below in a small moulding. On each side of the web is riveted a wide angle-iron which, when the rail was bedded in the ballast, would give the requisite bearing surface. If used on transverse sleepers the web and angle-irons were to be let into them. Its weight is 132 lb. per yard. M.202.

842. Rail and chairs, 1857. Presented by C. E. and C. Stretton, Esqs., 1903.

These formed a portion of the permanent way laid in 1857 on the line between Leicester and Hitchin. The rail is of reversible section and was rolled in 20 ft. lengths, which were jointed by fish-plates. The chairs were secured to transverse wooden sleepers by two spikes, and the rails were fixed by wooden keys placed at the inner side of the rails. This method of keying was adopted with the object of maintaining the gauge even if the keys loosened; after some years' trial, however, it was decided that considerable breakage of the chair jaws resulted therefrom, and since about 1884 the Midland Railway Co. has abandoned it in favour of the usual outside keying.

The rail now weighs 75 lb. per yard (originally 80 lb.), the chairs 32 lb. each, and the fish-plates 21·5 lb. per pair. M.3305.

843. Railway chair and rail joint. Presented by James Morris, Esq., 1861.

This joint was patented by Mr. Morris in 1857, and was for use with reversible double-headed rails. It is made by keying into a special chair, rubber insertion being also added. M.208.

844. Elongated joint chair. Contributed by R. J. Badge, Esq., 1858.

This arrangement, patented in 1857 by Mr. Badge, is a combined fish-plate and chair. It is composed of two equal and similar pieces, which are

bolted together through the rails ends and act as fish-plates, while the bottom edges of these plates are enlarged so as to form feet for securing them to the sleeper. The nuts are prevented from slacking back by a small wedge, driven between the under side of each nut and a projection on the chair.

Inv. 1858–11.

845. Wrought iron rail. Presented by Messrs. J. and C. Thompson, 1892.

This is a parallel double-headed wrought iron rail with a fish-plate joint, and represents the general pattern in use before the introduction of steel. Weight per yard 56 lb., weight of chair 22 lb. Steel rails were first used experimentally in 1862, with steel at 15*l.* per ton, but even at that price proved economical through their great endurance. Since 1870 steel has gradually replaced iron, so that now wrought iron rails have become as scarce as those of cast iron. M.2494.

846. Bridge rail. Contributed by Thomas Ellis, Esq., 1862.

The feature of this rail, patented by Mr. Ellis in 1861, is that when being finally rolled the flanges are closed together so as to leave no longitudinal space, the intention being to secure better bearing surface. It is believed to have been used on the Great Western Railway. Its weight is 62 lb. per yard. M.778.

847. Bridge rail. Presented by the Lady Superior, Convent of the Sacred Heart, Paignton, 1913.

This is an example of the bridge rail used on the Great Western Railway; it is of steel, and is of similar section to the rails used on that line about 1860.

It is 2 in. wide on the tread, 2·5 in. high, while the flange is 5·5 in. wide and 0·31 in. thick. The head of the rail, and the arch beneath it, have sloping sides, probably to facilitate rolling. The rail is much corroded and now weighs 41·7 lb. per yard, but when new would weigh about 62 lb. per yard. The rails were fixed by screw spikes to 12 in. by 6 in. longitudinal sleepers, which rested upon 6 in. by 4 in. transverse sleepers placed 5 ft. apart. The gauge of the rails was 7·04 ft. M.4207.

848. Rail and chair (1875). Presented by C. E. and C. Stretton, Esqs., 1904.

These were known as the improved Settle and Carlisle pattern, and were laid on the Midland Railway in 1875. The rail is of steel, bull-headed, weighed 83 lb. per yard, and was rolled in 24 ft. lengths; the joints were fished. The rails were secured in the chairs by wooden keys placed on the inner side of the rail, whilst each chair was fastened to its wooden cross sleeper by two trenails and two spikes. The rail now weighs 70 lb. per yard and the chair 39 lb. M.3325.

849. Rail, joint and chairs (1893). Presented by the Midland Railway Co., 1893.

This is a specimen of the permanent way used on the main line of the Midland Railway in 1893. Two short lengths are shown jointed together with the standard steel fish-plates and bolts, the nuts of which are prevented from slipping back by a locking arrangement which consists of four radial slots on the outer face of the nut, by which a certain elasticity is given to the nut. Two of the company's chairs are also shown, each of which is secured by two spikes and two trenails to transverse sleepers. The rails, which are of steel and cut to 30 ft. lengths, weigh 85 lb. per yard, and the cast iron

chairs 50 lb. each. The sleepers are rectangular, 9 ft. long, 10 in. wide, 5 in. thick, and are placed at distances of 2·78 ft. centre to centre, reduced to 2·17 ft. where there is a joint intervening. M.2540.

850. Rail and chair (1907). Presented by the Midland Railway Co., 1907.

These are specimens of the rail, chair, and fastenings used on the Midland Railway in 1907. The rail is of steel of the bull-headed pattern and weighs 100 lb. per yard, rails of this weight having been introduced on this railway in 1896. The chairs, which weigh 65 lb. each, are secured to transverse sleepers by two spikes and two trenails; the sleepers are 10·5 in. wide, 5 in. deep, and 9 ft. long. M.3518.

851. Drawing of rack rails. (Scale 1 : 2.) Presented by the Swiss Locomotive and Machine Works, 1909.

This drawing shows the construction of the principal forms of rack rails used on mountain railways. All are placed centrally between the running rails.

The Riggenbach rack consists of two channel-irons placed back to back a few inches apart, while trapezium-shaped cross-bars, forming the rack teeth, have their ends riveted into the webs of the channels. The lengths of rail are joined by fish-plates, and are bolted to transverse steel sleepers; the thrust is transmitted to the sleepers by short pieces of angle iron riveted to the lower flanges of the channels (*see* No. 252).

The Abt rack consists of two vertical flat bars, having teeth milled along their upper edges, placed side by side a short distance apart, and with their teeth stepped. At the middle and ends the bars are bolted to chairs, which are in turn bolted to transverse steel sleepers (*see* No. 253).

The Strub rack, used on the Jungfrau Railway, is a simple vertical one in which the teeth are cut in the deep head of a flat-footed rail which is supported on short pieces of channel iron bolted to steel cross sleepers. At the joints the lengths of rail are connected by angle fish-plates, and the channels extend from one sleeper to the next.

The Locher rack consists of a double-headed rail, with teeth cut in each head, laid on its side and riveted to a longitudinal saddle-shaped rail, which is in turn bolted to channel-iron chairs riveted to steel cross sleepers. The joints are made by longer channels bridging two sleepers (*see* No. 254).

M.3702.

852. Bowl sleeper (1859). Presented by Messrs. Ordish and Le Feuvre, 1862.

The bowl sleeper was first patented in 1846 by Mr. H. Greaves and was soon afterwards successfully used by Robert Stephenson in Egypt.

It is an inverted spherical bowl in cast iron with the jaws of a chair formed upon it, and is provided with two side holes by which ballast can be packed within. One jaw of the specimen shown is provided with vertical serrations for use with the spring key patented in 1859 by Mr. R. M. Ordish. The weight of the casting is 91 lb. M.853.

853. Bowl sleeper. Presented by Messrs. Wilsons, Pease & Co., 1895.

This sleeper is used on some Indian railways. It consists of an elliptical cast iron bowl, with lugs on the upper surface forming the jaws of a chair for holding a flat-footed rail. The rail is secured by a wooden key, and rests on bearers at the extremities of the bowl. The gauge is maintained by a wrought-iron tie, held in a transverse socket formed in the casting. Two holes are provided for packing the ballast into the bowl. The sleeper weighs 64 lb. M.2757.

854. Plate sleeper. Presented by Messrs. Wilsons, Pease & Co., 1895.

This form of metal sleeper was first patented in 1853 by Mr. C. de Bergue, and was tried on several British lines; it was found, however that the arrangement, although reducing the first cost, was not so suitable for heavy traffic as wooden sleepers carrying chairs.

The modern example shown, which is used on some lines in Spain, consists of a rectangular cast iron plate with a central rib below, modified to receive and retain a notched tie of wrought iron. The plate is extensively ribbed on its upper surface, and the flat-footed rail used is supported on four of the transverse ribs, while ledging against a longitudinal one. There are no chairs, the rails being secured by a clip held down by a bolt; this bolt also fastens the tie-rod which passes through a slot in its shank. The sleeper weighs 62 lb.

M.2756.

855. Steel sleeper and chairs. Lent by F. W. Webb, Esq., 1888.

This is portion of the permanent way patented by Mr. Webb in 1879, and laid down experimentally on the London and North Western Railway in 1884.

The sleeper is of steel plate, pressed into a trough form to give stiffness, and with the ends bent down to retain the ballast and prevent lateral movement. The chair jaws are steel stampings riveted to the sleeper, but with an interposed plate and two beddings of tarred felt. The bull-headed rail used is secured by the usual wooden key or by the spring steel key shown in one of the chairs.

M.1938.

856. Chairs and sleepers in forged steel. Presented by James Muirhead, Esq., 1897.

This construction of forged chair was patented by Mr. A. E. Muirhead in 1894. A suitably rolled or stamped billet of steel is taken and so cut as to leave two flaps, which, when bent upward, will form the jaws of the chair. With flat-footed rails shallow jaws only are necessary, between which the foot is secured by a metal key. These chairs are cut from a billet having a central rib, which on either side of the jaws is flattened down, so increasing the bearing surface. If the chairs are held simply by iron ties without sleepers, the ends are bent down and slotted as shown. The combined sleeper and chairs for double-headed rails have the rails secured by the usual wooden key, but otherwise are free from joints and loose parts. It is claimed that a forged steel chair weighing 24 lb. is considerably stronger than a cast iron one of 41 lb. weight.

M.2979.

857. Model of Wood's steel sleeper and rail fastening. (Scale 1 : 2.) Lent by C. Wood, Esq., 1893.

The sleepers are of steel and of trough section, slightly open at the extreme edges. The rails are of the flat-footed type, and no chairs are used. The fastening consists of a steel clip of a C form, which is passed upward through two slots punched in the sleeper. One extremity of the C hooks on to the foot of the rail and the other receives the wooden key, which is driven in between it and the web and foot of the rail, so tightening the whole simultaneously.

M.2549.

858. Howard's steel sleepers. Made by Messrs. J. and F. Howard. Received 1895.

Two forms of these sleepers for light or portable railways are shown; the rail used is flat-footed and the sleeper consists of a steel plate corrugated upwards along the centre, and curved downward at the edges. The centre

corrugation is cut away at two places, so leaving jaws. Into these the rails are fitted and secured by metal keys, which have notched sides to prevent working back. For joint sleepers, or for heavy work, two corrugations are formed on each sleeper; in addition to forming the chair the corrugation greatly stiffens the plate. M.2896.

859. Steel sleeper and rails. Presented by Messrs. W. G. Bagnall, Limited, 1899.

These are part of a narrow gauge line suitable for being worked by a six-wheeled locomotive weighing 20 tons.

The sleeper is of steel plate 0·25 in. thick, and by pressure is given two longitudinal corrugations, while at the same time the ends are turned down.

The rails are flat-footed, and weigh 41 lb. per yard; they are held between clips, pressed up from the solid plate, and secured by a key. These sleepers were patented by Mr. W. G. Bagnall in 1889. M.3058.

860. Models of portable railway plant. (Scale 1 : 8.) Lent by Messrs. John Fowler & Co., 1892.

Portable railways of gauges from 16 in. to 30 in. are frequently employed when the traffic is not sufficiently permanent to warrant the construction of an expensive road. The rails and metal sleepers are bolted together, forming complete sections of 15 ft., which can be rapidly moved or laid down on the surface of the ground. Horses or men usually do the hauling on the lighter lines, and small tank locomotives on the heavier.

These models show various details of the portable railway patented by Mr. A. Greig in 1879. The steel rails are flat-footed, weighing from 10 lb. per yard upwards, in 15 ft. lengths, and carried on corrugated steel sleepers spaced at 3·75 ft. centres, but more closely where the ground is bad. Each sleeper has a deep longitudinal corrugation pressed into it, and at the ends is riveted a steel chair, cut from a bar so rolled as to fit closely the flange and web of the rail on one side. The rail is held into the chair by a hook bolt, which grips the inner edge of the rail flange and passes under the rail and chair by the groove in the sleeper to the end, where it is tightened up by a nut. The lengths are joined together by sleepers of double width and two corrugations, the long chairs acting as fish-plates, but the rails are not drilled, hook bolts being employed throughout. A turntable and crossings are also shown, in which the method followed is to make up such pieces complete, and finish with the ordinary attachments. A short length of inclined rail is used instead of points when a temporary branch only is required. The trucks shown have channel-iron frames and timber stanchions. In one case the channel iron is carried round to form the buffers, and the draw-bars swivel on a pin attached below the platform at the centre, so that the animal employed in hauling can pull from the side of the line without risk of derailing. M.2427.

861. Drawing of tram road parting. (Scale 1 : 16.) Prepared in the Museum from information supplied by the Great Western Railway Co., 1915.

This is a reproduction of a drawing made in 1808 and sent by Mr. Richard Fothergill, of the Tredegar Iron Works, to the Monmouthshire Canal Co. at Newport, to direct the block layers when putting down the passing places on parts of their tramroads then under reconstruction or repair. The line from Newport to Tredegar was authorised in 1802 and was laid out by John Hodgkinson under the direction of Benjamin Outram; it was completed in 1805.

The drawing shows the lay-out of a junction or "parting" on a plateway. The switch and crossing plates are indicated, there being a movable tongue on one line only; outer guard flanges were cast on the plates opposite the crossing plate, and all the plates forming the two inner lines were similarly provided with two flanges, probably to prevent them from being obstructed

by the ballast disturbed by the horses' feet. The plates were 3 ft. long and laid to a gauge of 50 in. between the flanges, that being the distance advocated by Outram. The ends of the rails were widened by ears and were secured to the stone sleepers by a spike passing through a hole formed by notches cast in the adjacent rail ends. The drawing shows also the different forms of ear used on plates made for this company. Inv. 1915—46.

862. Rail crossing or "frog," 1832. Presented by the Bagworth Colliery Co., 1903.

This cast iron crossing was employed on a branch line laid in 1832 by Lord Maynard from the Leicester and Swannington Railway to his collieries; it is, however, very similar to those in use on the main lines of the period until, with the increase in speeds, the construction was found to be unsafe for general traffic.

The crossing consists of a flat bed having raised portions forming continuations of the lines of rail with spaces between, for the passage of the wheel flanges, while two raised outside guards are also provided which prevent the wheels leaving the track when passing the gap. The crossing is 4·25 ft. long by 1 ft. wide, and has an angle of 10 deg.; it was spiked down to sleepers, and the rails, which were held in their separate chairs, simply butted against its ends. M.3309.

863. Sliding-rail switch. Presented by C. E. and C. Stretton, Esqs., 1900.

This is from the Leicester and Swannington Railway (1832–46), and illustrates a kind of switch much employed at that period. The rails are of the fish-bellied pattern, but the portion arranged for shifting is a 2 in. sq. bar, 11·8 ft. long, riveted to a length of 6·5 in. by 0·5 in. flat plate; it is pivoted at one end, and the other would be attached to a rod moved by an eccentric on the end of a vertical shaft, as shown in adjacent views of the London and Birmingham Railway in 1838. The double and half chairs necessary for the switch are also shown. M.3111.

864. Model of sliding or stub switch. (Scale 1 : 12.) Made in the Museum, 1902.

This shows the complete arrangement of the class of switch in common use in England till about 1850, and still employed on some of the Colonial branch lines. The model shows a three-way switch in use in Belgium in 1858.

The rails are of a double-headed pattern, but the portion arranged for shifting is of square bars riveted to flat plates, which slide on iron bearers arranged transversely on longitudinal sleepers. The square rails are each pivoted at one end, and attached by a rod near the other to a crank in a vertical shaft, which can be locked in the three working positions. With only two roads the crank-throw limited the two positions without accurate locking, but with three roads the intermediate position introduced a serious element of danger. This form of switch was sometimes arranged with a movable portion for each road, so as to distribute the wear over several pivoted bars. M.3231.

865. Model of facing points (working). (Scale 1 : 4.) Contributed by Messrs. Wilkinson and Crowther, 1875.

This represents the arrangement of facing points with safety locking apparatus, patented by Messrs. C. H. Wilkinson and E. Crowther in 1873.

The point rails are parallel and of T section; one end is hinged and the other slides laterally so as to permit of being brought into alignment with either the main or the branch line. These rails are supported throughout

their length by tapering box-shaped castings, secured in chairs, and having within them sliding locking bolts which hold the points in either position. Upward projections are formed on the bolts and corresponding openings in the point webs, so that the points cannot be shifted until the bolts are moved so as to bring these opposite to one another. Other small projections on the bolts cause the point rails to be slightly raised when the bolts are moved, so that such movement cannot take place while a train is passing. The points and bolts are actuated by separate levers. M.1374.

866. Railway points and crossings. (Scale 1 : 12.) Made in the Museum from information supplied by the Midland Railway Co., 1913.

These three models show the construction of the points and crossings used with 100 lb. rails on the Midland Railway in 1902–5.

The points are of the spring tongue type in which the switch rails have no fish-plate hinge but are rigidly connected with the continuing rails, the spring of the rail itself being relied upon to give the necessary lateral motion. In the 12 ft. points shown the switch rails are 30 ft. long and their ends are planed for 7·5 ft. and so shaped that they fit snugly against the stock rails. They are rigidly fixed in chairs up to 17 ft. from the tips, and the moving ends slide on flat single-sided chairs bolted to the stock rails. The points when close to their stock rails are supported by studs placed below the wheel flange level. The points are connected near the ends by two cranked rods secured by cotter pins, and the operating rod is similarly fixed to one of them. A steel sole plate is placed on the sleeper immediately under the point tips.

In the 1 in 8 common crossing the main and branch lines from one side meet and are set over, planed and bolted together so as to form a solid point. The two rails from the other side are set outward to give the necessary wheel clearance, and all are securely keyed in the special chairs shown. The rails are all 24 ft. long.

In the 1 in 8 diamond crossing, the main and branch lines form one wing rail bent at their junction; the continuations of the two rails end as points which are set and planed so that the web remains in the centre. Opposite to the wing rail a check rail 16 ft. long is placed. Inv. 1913–122 to 124.

867. Compressed trenails and keys. Contributed by Messrs. Ransome and May, 1857.

These specimens were made by the process patented by Messrs. J. Ransome and C. May in 1841, for the preparation of the trenails and keys for fixing railway chairs to the sleepers and the rails in the chair; they were first used on the South Eastern Railway. Prior to this invention the trenails and keys were compressed, so that they should expand when in position and remain fast, by driving them through iron rings or dies; unless used immediately, however, they were found to have regained their original size to such an extent as to be unreliable.

In the improved process the oak, or other hard wood blocks, are forced into iron moulds by a powerful press, and then baked in an oven for several hours, so that when removed from the moulds they retain their reduced size. After being driven into the sleepers or chairs they absorb moisture and swell sufficiently to insure a firm hold. The compression reduces the bulk of the trenails 37 per cent. and of the keys 20 per cent. Inv. 1857–15.

868. Barlow's iron key. Presented by the Midland Railway Co., 1903.

This form of railway chair key, patented by Mr. W. H. Barlow in 1844, was introduced to replace the wooden keys which, although satisfactory in the intermediate chairs, frequently became loose or suffered damage through the rocking of the sleepers when used in joint chairs.

Barlow's key consists of a strip of iron plate bent to form a flattened tube, with the joint open or else closed by welding; it accordingly possesses some elasticity with great strength and durability, and was found to be very effective in stiffening the joints. These keys were first used on the Midland Counties Railway, but, owing to the introduction of jointing by fish-plates shortly afterwards, were never extensively adopted. In recent years they have been employed in some of the "all metal" permanent ways.

The example shown was in use till 1903, and now weighs 3 lb.; it is 6 in. by 3·5 in. by 1·75 in. and the metal is 0·25 in. thick. M.3311.

869. Railway key fastening. Contributed by E. Gatwood, Esq., 1860.

A chair and piece of double-headed rail are shown, having the wooden key fitted with a fastening to prevent slacking back as the wood shrinks. The fastening consists of a strip of sheet steel split at the end, and with the tongues bent in opposite directions, so that one catches the chair while the other is slightly embedded in the smaller end of the key. M.395.

870. Clip for chair key. Lent by Messrs. Turton Bros. and Matthews, 1890.

This clip, patented in 1885 by Mr. G. A. Goodwin and Mr. W. F. How, is designed to prevent the wooden keys employed to secure railway metals in their chairs from working back, owing to the vibrations caused by passing trains and the shrinkage due to the action of the weather.

The specimen shows a modern chair with a short length of rail keyed in position and the key secured by the clip. The clip is stamped from flat steel and the ends are bent over to secure it in the chair. Two spring tongues are formed in the middle of the clip and these, while offering no resistance to the insertion of the key, act as ratchet pawls and dig into the wood when any movement is attempted in the reverse direction. Rails so secured have been known to creep 0·75 in. against the keys without any slackening taking place. When necessary, however, the keys can be driven out by a heavy hammer. M.2304.

871. Spring washers. Presented by Messrs. Grover & Co., 1875 and 1890.

Spring washers were introduced in 1873–5 by Mr. J. W. Grover as a means of preventing nuts from slackening back under vibration; they have been extensively used for the fastenings of fish-plates.

The washer consists of one turn of a helix, made in tempered steel, with the ends so bevelled that screwing down the nut simply flattens the helical turn into a ring, but the reverse motion causes them to cut into the surface of the nut and the fish-plate. The washer is made from a piece of steel of the required length, which is gripped between a lever and a mandrel and bent whilst hot between two helical cheeks. In 1886, however, Mr. Grover introduced a modified form of the washer by making it from rod of H section, with the object of attaining increased compressive resistance without adding to the weight. M.1766 and 2329.

872. Rail lifter. Lent by Messrs. De Bergue & Co., 1892.

This is a form of screw-jack for lifting rails that have settled, thus avoiding the use of a long and inconvenient lever otherwise necessary. It is placed on the ballast and under the rail, and will lift the rail and the adjacent sleepers, so enabling the ballast to be repacked where necessary.

It consists of a wide cast iron shoe, to give sufficient bearing on the ballast, enclosing a wrought iron lever, having its fulcrum at one extremity and at the other containing a bronze nut through which works a screw,

bearing on the shoe. Handles are fixed for carrying, and a T key for turning the screw is provided, by which one man can exert sufficient power to raise any rail or point. The weight of the lifter complete is 66 lb.

M.2464.

873. Model of turntable for rolling-stock. (Scale 1 : 12). Contributed by T. Dunn, Esq., 1857.

This construction of turntable was patented by Mr. Dunn in 1850, and is intended for sidings or warehouse floors where shallow foundations only are permissible. The supporting rollers project above the table, and all parts are accessible from above.

There is but one set of rails, and they are supported on girders connected by cross pieces with the centre pivot; the intervening spaces are planked over.

M.71.

874. Model of turntable for rolling-stock. (Scale 1 : 12.). Lent by the Taff Vale Railway Co., 1896.

This table is contained within a cast iron casing, at the bottom of which is an eight-armed foundation ring that forms the track for the carrying rollers, and also supports the socket for the central pin. The weight of the table is carried by an inner live ring with five rollers and an outer one, which is flexible vertically, having ten rollers.

The table is cast in halves and bolted together; it has a roughened surface and two sets of rails intersecting at right angles. Below, it is ribbed and provided with two roller tracks and also with a central guiding pin. M.2959.

875. Models of traversers for rolling-stock. (Scale 1 : 8.) Contributed by T. Dunn, Esq., 1857.

The traverser is an arrangement patented by Mr. Dunn in 1847–50 for moving a railway carriage sideways from one line of metals to another, possibly a considerable distance away. It consists of a very low truck, carried on wheels, which run on special transverse rails fixed where the traverser is used. The truck carries two low rails, with hinged tapering ends, or ramps, by which the carriage can be mounted from the main rails to those on the traverser without serious difficulty. Inv.1857–13.

876. Model of railway level-crossing gates. (Scale 1 : 6.) Presented by A. Vickers, Esq., 1862.

This is an arrangement for simultaneously operating the four gates of a level crossing; it was patented by Mr. Vickers in 1859. The gate posts are rotated by means of worm wheels attached to their lower ends and driven by worms and shafting connected by bevel gearing. One shaft is operated by a hand winch, and the worm gearing, being irreversible, effectually prevents the gates from being moved except by the winch. M.805.

877. Literature of early railways. Presented by C. E. and C. Stretton, Esqs., 1900, and W. C. Cater, Esq., 1907.

These comprise maps, guides, regulations, tables of fares, etc., relating to the Liverpool and Manchester, Grand Junction, London and Birmingham, London and Southampton, and other railways.

A copy of Bradshaw's *Railway Companion* of 1842 is shown in the same case. M.3090, 3109, and 3510.

878. Early railway ticket. Presented by C. E. Stretton, Esq., 1888.

This ticket was in use on the Leicester and Swannington Railway (*see* No. 205) from 1832 till 1846. It is a bronze casting, and the inscription

appears to have been obtained from the mould; the reverse bears simply the number 20. A passenger going to Bagworth from any other station would have such a ticket issued to him, the ticket number and the fare paid being recorded in a book. The guard of the train carried a collecting box having a separate division for each station, and after collecting the tickets returned them to the various stations for future use.

An adjacent photograph shows the West Bridge station and booking office of the line on which these tickets were issued. M.1920.

879. Hawksley's stair tread. Contributed by Joseph Westwood, Esq., junr., 1870.

This is an original specimen of the stair tread patented by Mr. G. Hawksley in 1865. It was laid down experimentally at Dalston Station in 1867, and taken up after three years' service, during which time over six million passengers walked over it, with the result that the surface was only lowered 0·06 in.

The step consists of a cast iron grating of small squares, each square being filled in with a renewable block of wood set with the grain on end, flanges at the bottom of each square forming a bearing for the blocks. By placing the wood with its grain in this position the particles of grit on the boots are pressed into the ends of the fibres, and so tend to harden the surface while giving a secure footing. The blocks are made of oak, pitch pine, or deal, according to their position on the tread and the wear that will take place in consequence. M.1196.

880. Photographs and details of aerial ropeways on the "Otto" system. Presented by Messrs. Commans & Co., 1892.

These wire ropeways have a heavy fixed carrying rope and a light travelling hauling rope, but to secure a return service there are usually two carrying ropes, and the hauling rope is endless and kept continuously moving at a speed of about 3·5 miles per hour. A carrying rope 1·375 in. diam. and a hauling rope 0·625 in. diam. are proportions that have been used. The carrying ropes are supported on standards of timber or wrought iron placed at about 200 ft. apart, but spans of 1,000 ft. to 1,600 ft. have been sometimes employed. The carriers or skips are suspended from two-wheeled trollies (as shown) which run on the standing rope, and are provided with a clamp by which the hauling rope can be seized and so caused to move the load. When the delivery station is reached a bar fixed there strikes a lever on the clamp, and so automatically disengages the hauling rope, and the trolley and load by their momentum may run on and up a rigid iron turn-out or shunt where loading or unloading may be carried on. When the inclines do not exceed 1 in 6, a simple frictional grip of the clamp is sufficient; for inclines up to 1 in 3 clamps with corrugated jaws are used, while for still steeper slopes the hauling rope has collars inserted in it which enable the clamps to hold by a positive grip, but in such cases it is desirable to start the load by hand before engaging, so as to reduce the shock. An actual trolley is shown, together with an example of the frictional and of the positive grips employed.

A ropeway in Spain on this system 9·69 miles in length is in four sections, a 30 h.p. engine driving the first two sections, and one of 70 h.p. the last two. There are 660 buckets on the line, and the capacity is 4,095 ton-miles per day of 10 hours. M.2478.

881. Drawing of the atmospheric railway system. (Scale 1 : 24.) Made in the Museum, 1913. Photograph presented by the Great Western Railway Co., 1912.

The idea of transporting merchandise or passengers by means of atmospheric pressure was worked at early in the 19th century by several inventors, including Medhurst, Vallance and Pinkus, but the system was brought to a

practical issue by Messrs. S. Clegg and J. Samuda, who patented improved apparatus for the purpose in 1839 and 1844 respectively. In this system a cast-iron pipe or cylinder was laid between the rails, and within this moved a piston connected with the train by a bar which passed through a continuous slot formed along the top of the pipe. The slot was closed by a leather flap valve hinged along one edge and sealed at the other edge by a mixture of tallow and wax. The valve was lifted up, behind the piston, by rollers attached to the connecting bar, so that when the length of pipe in front was exhausted of air by a stationary pumping engine, the train was propelled by the atmospheric pressure acting on the back of the piston. After the passage of the piston the valve was closed by other rollers and sealed by a heated bar.

An experimental line was laid on part of the West London Railway, near Wormwood Scrubs, in 1840, and such success was attained that the system was adopted on the Dalkey branch of the Dublin and Kingstown Railway, 1·75 miles long, where it worked from 1843 to 1855; it was also applied to a short incline on the Paris and St. Germains Railway where it was in use until about 1860. Its suitability for lines of more general character was tested on 7·5 miles of the London and Croydon Railway, between New Cross and Croydon, in 1845–6, but although high speeds were attained at times, it was abandoned after a few months working. Brunel was so impressed with the possibilities of the system that he advised its adoption on the South Devon Railway, between Exeter and Plymouth, the construction of which was authorised in 1844. The apparatus was accordingly installed, and set to work in 1847 on 20 miles of single line (*see* No. 882), but after 12 months' trial locomotives had to be used instead. The failure of the system was mainly due to the difficulty of keeping the longitudinal valve properly sealed, the loss of power from leakage being very great. It also possessed the inherent defects of the stationary engine system, which have only been overcome or minimised by the use of electrical transmission of the power to the trains.

The drawing shows the mechanical details of the atmospheric system as originally designed by Messrs. Clegg and Samuda, but various modifications were made on the lines actually constructed. The photograph shows a drawing of the means to be employed for protecting the pipe and valve at level crossings. M.4104 and Inv. 1913–66.

882. Portion of air cylinder from the South Devon Atmospheric Railway. Presented by the Lady Superior, Convent of the Sacred Heart, Paignton, 1913. Map of the line and views taken during construction, 1847. Prepared in the Museum, 1913.

The South Devon Railway, between Exeter and Plymouth, authorised in 1844, is notable as having been the scene of the crucial experiment with the atmospheric system of railway propulsion (*see* No. 881). This system was adopted by Mr. I. K. Brunel because it appeared from Messrs. Clegg and Samuda's earlier experiments to be extremely promising, but events showed that while comparatively successful for very short special lines, it was impracticable for ordinary railways of considerable length.

The atmospheric apparatus was installed between Exeter and Totnes, a distance of 29 miles, and regular working commenced between Exeter and Teignmouth on September 8th, 1847, and shortly afterwards to Newton, a total distance of 20 miles; it does not appear to have been worked between Newton and Totnes, although the pipes and pumping engines were provided. The system ceased working on September 9th, 1848, mainly owing to the failure of the longitudinal valve. The line between Exeter and Newton was comparatively level, pipes 15 in. diam. being used, but between Newton and Totnes severe gradients were met with so that 22 in. pipes were laid. An expanding piston was designed capable of fitting both sizes of pipe. There were eight engine houses between Exeter and Newton, placed a little under 3 miles apart, and these produced a vacuum in the pipe of about 20 inches of mercury, equivalent to an air pressure of 10 lb. per sq. in.

The air cylinder was of cast iron in 10 ft. lengths united by spigot and socket joints packed with yarn and tallow. It was not bored, but was coated inside with tallow to reduce the friction of the piston, which was packed with a cup leather. The valve seating was planed, and the valve consisted of a double strip of ox-hide riveted between a series of iron plates about 12 in. long; the inner plate fitted into the slot and completed the circumference of the pipe, while the outer plate was somewhat wider. The valve was held along one edge by a round iron bar drawn down, so as to grip the leather, by a series of inclined hook bolts passed through holes in a vertical flange forming one side of the valve housing. A space was left between the opening edge of the valve and another vertical flange at the edge of the seating, and in this was placed the wax and tallow mixture with which the valve was sealed. The bar connecting the piston with the train passed out of the slot obliquely, so that the edge of the valve only required a lift of about 1·5 in. The air cylinder was divided into sections by inlet and exit valves which were opened by the train as it approached them.

The length of cylinder shown is 22 in diam. inside, and was removed from the beach at Paignton, where it had been used with others for many years as a surface water drain, hence its corroded condition.

M.4185 and Inv. 1913–64 and 65.

683. Pneumatic despatch switch. Received 1901.

Several schemes had been proposed for transmitting objects by blowing them through a tube by air pressure, but it was not till 1851 that Mr. J. Latimer Clark introduced the method on a practical scale by laying a tube for conveying telegrams for the Electric and International Telegraph Co. between their stations in Telegraph Street, Cornhill, Lothbury, and Mincing Lane. Similar arrangements were installed at Berlin in 1865 and at Paris in 1866, while in 1865 the Pneumatic Despatch Co. constructed a D-shaped tube, 4 ft. high by 4 ft. 6 in. wide, from Euston to Holborn, which was subsequently extended to the General Post Office, for the conveyance of parcels and goods in four-wheeled trucks directly propelled by air pressure.

In 1867 Sir C. W. Siemens patented a pneumatic circuit in which the carriers were driven through the transmission tube in one direction only, so that several carriers could be passing through the tube at the same time, and their propulsion was effected by reducing the pressure in front of the carriers as well as increasing that behind them. In 1870 he laid a return circuit on this system, consisting of two tubes 3 in. diam., between Telegraph Street and the General Post Office, a distance of 852 yd., worked by an air pressure of 7 lb. per sq. in. above atmosphere and an exhaustion of 5·5 lb. below.

In 1873, however, Mr. R. Sabine determined that tubes of 2·25 in. diam. and an air pressure of 10 lb. per sq. in. above atmosphere and an exhaustion of 6·5 lb. below would be more suitable, and these are the arrangements that have since been employed. The tubes are of lead, and are enclosed in iron pipes, while the carriers are of gutta-percha covered with shrunk drugget and weigh 2·75 oz. each. A carrier is introduced into or removed from the circuit by a switch of the form shown, which is a modification of the receiver and transmitter patented by Sir C. W. Siemens in 1870. It consists of two short lengths of tube mounted on a rocking frame, so that either length may be interposed between the end faces of the main tube; one length is clear throughout, while the other, or receiving tube, has a bolt across it to stop the carrier, which can then be removed by swinging over the switch. The receiver is provided, moreover, with a glass door, through which the carrier may be seen, or removed should the switch be blocked through two carriers arriving together.

M.3194

Street Tramways, etc.

884. Lithograph of early street tramway. Presented by R. B. Prosser, Esq., 1900.

Street tramways were first introduced in America, where, owing to the nature of the soil and a scarcity of stone, the roads had given exceptional trouble. The first line, laid between New York and Haarlem in 1832, underwent considerable vicissitudes, but ultimately the system extended, and by 1855 street tramways were in general use in several of the large American towns.

The first street tramway in England was laid at Birkenhead in 1860 by Mr. G. F. Train, an American merchant. He employed the stepped rail, adopted in Philadelphia in 1855, which had a raised ledge for the flanged wheels of the cars and a wide plate for the wheels of ordinary vehicles, thus resembling the double-purpose rail used in colliery districts as early as 1833 (*see* No. 827).

The tramway shown in the lithograph was from the Marble Arch to Notting Hill Gate, and was laid down by Mr. Train and opened in March 1861; he also laid similar lines from Westminster Bridge to Kennington Park and from Buckingham Palace to Victoria Station. These schemes had, however, failed to obtain Parliamentary sanction, so that when, owing to the great opposition aroused, the local authorities withdrew their concessions, the whole of the lines were removed, and tramways did not reappear in London till 1870, when the North Metropolitan line was opened.

Mr. Train's cars were 16·5 ft. long, 6·5 ft. wide, and 7 ft. high inside, while the wheels were of chilled cast iron and 2·75 or 3 ft. diam. M.3115.

885. Model of Loûbat's tramrail, 1853. (Scale full size.) Made in the Museum, 1913.

This represents the tramrail laid in Paris, by Mons. Loûbat, in 1853, on the first horse tramway constructed in France.

The rail was an iron bar with a groove along its upper surface to accommodate the flange of the wheel, while its under surface was of semi-hexagonal shape, and fitted on the top of a longitudinal wooden sleeper which was chamfered to receive it. Inclined spikes were driven through holes in the sides of the rail to secure it and an iron fish-plate was laid under each joint. The longitudinal sleepers, 4 in. wide by 6 in. deep, were laid on transverse sleepers 6 in. wide and 4 in deep, placed 6·6 ft. apart. The latter were notched to receive the former, which were fixed by wooden keys. The rail weighed 38 lb. per yard; it was 3 in. wide at the surface, the groove was 1·25 in. wide and 0·875 in. deep, while the tread was 1·125 in. wide. M.4186.

886. Model of early New York tramrail. (Scale full size.) Made in the Museum, 1913.

The rails used on the American street tramways, after their revival in 1852, were characterised by the very wide grooves provided for the flanges of the car wheels. The example shown represents the rails laid in Eighth Avenue, New York, about 1855.

The rail was an iron bar 5 in. wide and 1·5 in. thick, with a groove 2·25 in. wide by 1 in. deep, and a tread 2 in. wide. Small flanges along the lower edges served to centre the rails on longitudinal sleepers, to which they were fastened by nails driven obliquely through the flanges. The longitudinal sleepers were fixed on cross sleepers placed at intervals under them. M.4187.

887. Model of Train's step rail, 1860. (Scale full size.) Made in the Museum, 1913.

This represents the form of rail used on the first English street tramway that was laid at Birkenhead by Mr. G. F. Train in 1860 (*see* No. 884).

The rail weighed 50 lb. per yard, and was in the form of a flat wrought iron plate 6 in. wide and 0·56 in. thick, with a raised ledge or step along one side for the flanged wheels of the cars. The ledge was 1·5 in. wide by 0·75 in. high, and a small fillet was formed at each edge on the lower side of the plate. The rails were bedded on and spiked to longitudinal timber sleepers, 6 in. wide and 8 in. deep, which were let into and rested on transverse sleepers, and were spiked to them by means of iron knees. The gauge was 4·71 ft.

M.4188.

888. Model of flat tramrail, 1869. (Scale full size.) Made in the Museum, 1913.

This represents the form of rail that was adopted after Train's step rail had proved itself unsuitable. It was used at Liverpool in 1869.

The rail was a flat bar, weighing 45 lb. per yard, with a narrow groove for the wheel flanges and a small projecting fillet along the inner lower edge. It was 4 in. wide by 1·375 in. thick, while the groove was 0·75 in. deep and 1·25 in. wide at the top. The tread was 2 in. wide and the narrow ledge forming the other side of the groove was corrugated transversely. The rails were bedded on longitudinal timber sleepers 4 in. wide by 6 in. deep, and were secured by vertical spikes with countersunk heads flush with the bottom of the groove. They were fished at the joints with wrought iron plates let into the sleepers. The track was laid on a bed of concrete 7 in. thick, and concrete was also placed between the sleepers up to the correct level for supporting the 4 in. stone setts with which the street was paved. The sleepers were laid in and spiked to cast iron chairs placed about 4 ft. apart; the gauge of the rails, 4·71 ft., was fixed by bar iron cross ties, the ends of which were dovetailed into grooves cast in the chairs.

M.4189.

889. Livesey's rail and model of chair, 1869. Received 1913.

The early method of fixing the rails to the longitudinal wooden sleepers by vertical spikes (*see* Nos. 887 and 888) was found to be defective, and several improved forms of fastening were invented, the one shown being patented by Mr. J. Livesey in 1869, and used at Buenos Aires in 1870.

Livesey's system was an all-metal tramway in which the grooved rail was provided with a deep vertical flange at each side, and was supported on cast iron stools placed 3 ft. apart. The rail flanges were thickened downwards forming a dovetailed groove which fitted over the similarly shaped stool tops where it was secured by iron wedges driven in from below. The stools were bolted to longitudinal corrugated wrought iron plates 4·5 ft. long, while at the rail joints an extra stool was placed and the rails secured to it by wedge-headed bolts. The rails were tied to gauge by notched iron bars passing through slots in the stools and secured by keys.

The rail was 3·5 in. wide by 2·375 in. deep, and weighed 40 lb. per yard. The tread was 1·75 in. wide, and the groove 1·375 in. wide by 0·69 in. deep, while the narrow ledge on the opposite side of the groove was 0·25 in. lower than the tread.

M.4190.

890. Model of London tramrail, 1871. (Scale full size.) Made in the Museum, 1913.

After the failure of Train's tramways in London (*see* No. 884), nothing further was done until 1870, when the first section of the North Metropolitan tramways was opened. The rail and track used were similar to those at

Liverpool (*see* No. 888), but in 1871 the improved rail shown was adopted on other sections of the line.

The rail weighed 48 lb. per yard, and was 4 in. wide by 1·44 in. thick, with a groove 1·375 in. wide at the top and 0·75 in. deep. It had two fillets on the underside, which enabled it to be more firmly attached to the longitudinal sleepers to which it was spiked. The longitudinal sleepers were placed on transverse sleepers 5 or 6 ft. apart, and fixed to them by spiked angle plates situated at the outer side. The sleepers rested on a concrete bed, and the same material was used to fill up the whole space around them up to the level necessary for the paving material. M.4191.

891. Model of Larsen's tramrail and fastening, 1871. (Scale full size.) Made in the Museum, 1913.

The method of fixing the rails to the longitudinal timber sleepers by vertical spikes having been found unsatisfactory, an improved method with lateral fastenings giving increased strength and durability, was patented by Mr. J. D. Larsen in 1871, and used in London, Belfast, etc.

The rail was rolled with a deep flange at each side in place of the small fillets, and was fastened down by side staples, the upper points of which passed through the flange into the wood, while the other points were driven into the sleeper lower down. The staples consisted at first of flat plates with a hole at each end through which spikes were driven. The number of parts was then reduced by welding the upper spike on to the plate, while ultimately a simple bent iron staple or dog was used.

The Belfast rails were 3·87 in. wide by 1·5 in. thick, and weighed 62 lb. per yard; the tread was 1·87 in. wide, and the groove 1·125 in. wide by 0·94 in. deep. The gauge was 5·25 ft. The staples were of the two-piece type and were applied alternately to each side of the rail at short intervals. The rails were bedded on longitudinal sleepers which were laid on transverse sleepers and fastened to them by means of cast iron angle brackets. The sleepers were surrounded by concrete up to the underside of the paving blocks M.4192.

892. Model of tramway rails and sleepers. (Scale 1 : 4.) Lent by B. Barker, Esq., 1879.

This represents a form of permanent way for street tramways, patented by Mr. Barker in 1876, and laid down about that time in Manchester, Leeds, and other towns.

In this system a grooved rail of T section was supported on longitudinal cast iron sleepers which were practically continuous. Their bases were sufficiently wide to render concrete foundations unnecessary, and also served to support the adjacent paving setts.

The underside of the head of the rail where it rested on the sleeper was indented longitudinally, and the web was accommodated in a slot in the sleeper to which it was secured by transverse cotters. The lower part of the sleeper was a hollow casting with two flanges forming a base 12 in. wide. The total depth of rail and sleeper was 7·75 in. The rail was 3 in. in width, of which 1·5 inch was running surface; the weight was 40 lb. per yard. The sleepers were 35·5 in. long, and placed with 0·5 in. spaces between them, but on sharp curves shorter ones were used; they weighed 137 lb. each. M.1465.

893. Tramrail and chair. Lent by Isidore Spielmann, Esq. 1879.

This form of rail and chair, patented by Mr. S. Aldred in 1877, and improved by Mr. Spielmann in 1879, was used on a portion of the line of the London Street Tramways Co.

The rail is made in halves, which are reversible, and have an inclined plane of contact, so that by a single key they are both secured in a chair; as the

halves are so laid as to break joint, they do not require drilling or the use of fish-plates. The half rails were in 21 ft. lengths, weighing 32 lb. per yard, or 64 lb. together. The chairs were hollow castings 7·5 in. high, and weighed 37·5 lb. each; they were placed at 3 ft. centres and screwed to transverse wooden sleepers 6·5 ft. long, 9 in. broad, and 4·5 in. deep, bedded in concrete. In the later pattern the portion acting as a guard rail was given increased support. M.1467.

894. Model of Beloe's tramrail and chair, 1877. (Scale full size.) Made in the Museum, 1913.

This represents the tramway track patented by Mr. C. H. Beloe in 1877. It was used with wheels having a central flange and a tread on each side of it, an arrangement that required a minimum width of exposed metal, the whole of which was utilised by the wheels. It also rendered the variation of the width of the groove on curves a simple matter.

The rail was built up of two separate vertical bars 1 in. thick by 3·5 in. deep, placed side by side 1 in. apart, and supported on cast iron chairs to which they were bolted. The central groove thus formed was 1 in. wide and 0·875 in. deep. The bars were rolled with a shallow groove along one side which accommodated the bolt heads and nuts, so that the sides of the rail presented vertical surfaces to the adjacent paving setts. The chairs were spiked to transverse timber sleepers which were embedded in concrete. M.4193.

895. Early girder tramrail. Presented by Messrs. L. P. Winby & Co., 1906.

This is a specimen of the tramrail used in the system patented by Messrs. F. C. Winby and G. Levick in 1877, and laid down at Nottingham, Bradford and other towns. The rails laid at Nottingham in 1878 were the first girder rails rolled, but this specimen formed part of the line laid at Bradford in 1882. The girder form of rail, now universally used for street tramways, was patented by Mr. C. Burn in 1860, but it was not used practically on account of the difficulty of rolling the section. This difficulty was at first overcome by rolling the guard flange at right angles to the web and then bending it up, but the groove is now pressed in the solid head by an end roller in the finishing rolls.

In Winby's system, the girder rail had a narrow bottom flange and was bolted to a wide base-plate in order to obtain a good bearing on the road material and to support the pavement beside the rails. The rail was of steel, 6 in. deep, with a head 2·9 in. wide, and a running surface of 1·6 in.; the lower flange was 3·5 in. wide, and its weight was 58 lb. per yard. The base-plate was of wrought iron 12 in. wide and 0·25 in. thick; it was secured to the rail by cottered bolts. The plates were of one half the length of the rails and arranged to break joint with them. The rails were joined with steel fish-plates, and the gauge was fixed by tie bars. M.3465.

896. Model of Mackieson's iron tramway, 1880. (Scale full size.) Made in the Museum, 1913.

This represents the all-metal tramway patented by Mr. W. Mackieson in 1878, and laid on part of the Dundee tramways in 1880. The rail was of T section and with grooved head with a central dovetailed web below; this rested on and was keyed to longitudinal cast iron sleepers. The rails weighed 36 lb. per yard and were 3 in. wide by 2·19 in. deep, including the web which was 1 in. deep. The tread was 1·5 in. wide, while the groove was 1·06 in. wide and 0·63 in. deep. The rail was keyed to the sleepers by horizontal iron wedges introduced through slots cut in the floor of the groove; this fastening allowed the rails to be renewed without disturbing the paving. The sleepers were cast iron open frames 3·92 ft.

long, consisting of an upper grooved member 3 in. wide, and a lower flat plate 11·25 in. wide, connected together by vertical posts placed at intervals of 1 ft. The sleepers were laid on a bed of concrete and the spaces in them were filled with cement. No gauge ties were used. M.4194.

897. Model of Vignoles's rail and chair, 1881. (Scale full size.) Made in the Museum, 1913.

This represents the tramway permanent way patented by Mr. H. Vignoles in 1879, and used at Tottenham and Stoke-on-Trent in 1881. The rails were of the single-headed girder type supported in chairs which were fixed to timber cross-sleepers.

The rail was of steel, and weighed 42·5 lb. per yd.; it was 5 in. deep and had a grooved head 3 in. wide with a head tread of 1·5 in. The web tapered towards the bottom, where it was 0·375 in. thick. The rail was supported on one-sided cast iron chairs to which it was bolted, and large bearing plates, fitting closely against it, were placed under the nuts. At the joints the chairs were of double width and the bearing plates acted as fish-plates. The sleepers were 4 in. deep by 7 in. or 12 in. wide, and 6 ft. long, while the chairs were bolted to them. They were laid on a thin bed of sand placed on a concrete foundation, and were surrounded by concrete up to the level required by the paving blocks. M.4195.

898. Model of a cable tramway. (Scale 1 : 8.) Lent by Messrs. Dick, Kerr & Co., 1888,

The system of haulage by cable, although successfully applied in mines and on railways for many years, was not tested on street tramlines till 1873, when Mr. A. S. Hallidie and others introduced it on a practical scale in San Francisco, where the gradients are very steep. The first line in Europe worked on this system was the Highgate tramway, started in 1884; Edinburgh, Birmingham, and Melbourne are also well-known installations, but all except the first named have now been superseded by electric traction.

The model shows the general arrangement and details of the system as patented by Mr. Hallidie in 1875. An endless wire cable, several miles in length, is driven by a powerful engine at a station somewhere near the line, and travels below the road surface in a tube or conduit provided with a vertical slot at the top, 0·75 in. wide, and edged on each side by protecting rails; this slot is midway between the ordinary tramlines. The cable is supported at intervals by rollers, and directed by guide pulleys where the line curves, but for the better protection of the rope it is not arranged vertically under the slot.

The cable drives the car by a gripping appliance attached to the car and extending downward through the slot. Two forms of gripper, to the scale of 1 : 4, are shown; in one the relative motion of the two portions of the gripper is obtained by the use of a hand-wheel and screw, by which a wedge-shaped piece causes two jaws to grip or release the cable; in the other the jaws are moved by a combination of hand levers. When the gripper is holding the cable, it pulls it from the pulleys as it passes and thus clears them. The two special advantages claimed for cable haulage are, that in hilly districts the descending cars assist in hauling the ascending ones, and that uniformity of speed is secured. M.1927.

899. Electric tramway conduit. Presented by Messrs. R. W. Blackwell & Co., Ltd., 1905.

This is a section of an early tramway conduit of the form patented in 1888 by Messrs. E. M. Bentley and W. H. Knight, and used on some lines in the United States. Their first line was, however, laid down at Cleveland, Ohio, in 1884.

The conduit system of electric tramways, in which the conductors conveying the current are placed in an underground trough having a slot in the road surface for the passage of the collector, was developed from the cable system and introduced about 1883. Considerable attention was directed to perfecting it on account of the objection to overhead conductors, but notwithstanding its safety and unobtrusiveness, its much greater first cost has rendered it inapplicable except in the case of some of the larger cities, including London and New York. The first conduit line in this country was laid down by Mr. Holroyd Smith at Blackpool, in 1885.

The conduit consists of a number of U-shaped cast iron yokes placed 4 ft. apart, having their upper ends formed as boxes, level with the roadway. The slot is formed by two rails of obtuse angle section, resting on ledges and bolted to the yokes, the nuts being inside the boxes. The slot is 1·25 in. wide, but the rails may be packed behind to diminish this width. Each yoke box has near the bottom an opening into the conduit, and through this projects a porcelain insulator suspended by an iron bracket and carrying a tongue piece to which the conductor bar is attached. The boxes have movable covers so that the rails and conductors may be removed without disturbing the road surface. Between each pair of yokes is fitted a sheet iron trough forming the inner lining of the conduit and the whole was set in concrete either outside the track or between the rails.

There are two copper conductors 1·25 in. wide by ·25 in. thick, placed 3 in. apart, one carrying the high-tension current and the other forming an insulated return, thus obviating electrolysis. The current collectors or ploughs, of which two were fitted to each car, are flat frames containing insulated cores having at their lower ends steel-faced spring contact pieces which bear on the conductors. They have swivel and transverse motions and are mounted on swing frames to enable them to rise out of the slot should any obstruction be met with. The current was conveyed from the ploughs to the motors by cables.

The conduit measures 9 in. wide by 14 in. deep, but in modern examples larger dimensions have been found necessary. M.3395.

900. Model of conduit tramway crossing. (Scale 1 : 8.) Lent by the London County Council, 1909.

In the conduit system of electric tramways, in which the current is taken from conductors placed in an underground channel, special work is required at junctions and crossings in order to provide a clear passage for the tram-car plough which collects the current, while at the same time providing a strong and, as nearly as possible, continuous track for the cars and other road traffic. The model shows an example of such work for a junction of two tracks, made by Hadfield's Steel Foundry Co., Ltd., for the London County Council tramways, the conversion of which to electric traction commenced in 1902.

The conduit consists of an oval concrete channel, 14·5 in. wide and 17 in. deep, placed usually in the centre of the track; this is surmounted by pairs of steel Z bars, 7 in. deep, 30 ft. long, and weighing 61·5 lb. per yd., which form a central longitudinal slot 0·75 in. wide. These slot rails are bolted and stayed to the tops of U-shaped cast iron yokes, weighing 153 lb. each, which are placed 3·75 ft. apart, and embedded in the concrete. The running rails, which are 7 in. deep, 45 ft. long, and weigh 102 lb. per yd., as well as the paving, rest on a bed of concrete 6 in. thick, and they are stayed to alternate yokes. The joints are fished, and beneath them is riveted a short piece of inverted rail. The conductors are T-shaped bars of very mild steel, 30 ft. long, and weighing 21·5 lb. per yd.; they are placed 6 in. apart, and supported by ironclad porcelain insulators placed 16 ft. apart, and bolted to the lower flanges of the slot rails. Access boxes are placed over each insulator, and at every 200 yd. short pieces of the slot rail are removable for the insertion of the conductor bars.

At the junctions, the conduit is widened out into a large chamber which contains the point-working gear, and the rails and crossings are steel castings

supported on special yokes. The points of the running rails are 8 ft. long, and the slot junction, which is not in line with them, has a fixed tongue and two permanent slots into which the plough is guided by a pair of hinged slot-leaves working below the surface. These leaves are formed in the manner patented by Sir R. Hadfield and Mr. D. Galbraith in 1902, so that the large opening at the junction of the slots is partially closed by them. The points and slot-leaves work in opposite directions, and are connected together by a system of levers operated by a hand-lever at the roadside; a number of removable boxes are provided giving access to the mechanism. The wearing parts of the junction are fitted with renewable steel facings, and at the running rail crossings the grooves are made shallow so that the car wheels run smoothly over them on their flanges. Near the junctions, ploughs can be removed or inserted if necessary, through openings formed by short removable castings acting as portions of the slot rails; the conductors are here interrupted and spread out. M.3707.

Signalling.

901. Hand signal lamp. Presented by Messrs. J. Cowdy & Co., 1871.

This is an example of a one-handed signal lamp patented in 1868 by Messrs. W. A. Brown and R. L. Jones. The casing is cylindrical and has at the back a colza lamp with a concave reflector, and a flat glass in the door at the front. Between the oil lamp and the glass are three hinged "spectacle" frames connected with press knobs at the top, by depressing which either of the coloured glasses fitted can be placed before the flame. The knobs are moved by the thumb, and springs are added, which, when a trigger at the top is released, cause the glasses to swing upward into the top portion of the casing. M.1232.

902. Model of Liverpool and Manchester Railway signal. (Scale 1 : 16.) Made in the Museum, 1912.

This represents the earliest form of fixed signal, for day use, introduced on the Liverpool and Manchester Railway about 1834.

It consisted of a rectangular frame, on which a red flag was stretched, fixed to a vertical rod which was mounted in bearings attached to a wooden post. By means of a handle near the bottom, the flag could be turned so as to face the engine driver, when it indicated danger, or set parallel with the rails to indicate safety. Red and white lights placed on posts served the same purpose at night. M.4108.

903. Model of early cross-bar signal. (Scale 1 : 16.) Made by Messrs. G. Cussons, Ltd., 1912.

After the introduction of the simple fixed signals on the Liverpool and Manchester Railway (*see* No. 902), Mr. Edward Woods designed a more permanent arrangement, which was used on several lines, especially in Scotland.

The signal post was similar to an ordinary street lamp-post, and had a spindle running through it that could be turned through 90 deg. by a handle projecting through a slot. The top of the spindle at first carried a lamp with red and white glasses for the night signal, but a transverse red board, which turned with the spindle, was subsequently added for the day signal; finally, a board projecting on one side of the post was fitted so as to give a positive "clear" indication when the danger board was in the "off" position. The model shows the signal in its complete form. M.4075.

904. Model of ball signal, 1837. (Scale 1 : 16.) Made by Messrs. G. Cussons, Ltd., 1912.

This form of signal was introduced about 1837 on the Great Western Railway.

It consisted of a wooden post with a bracket and pulleys at the top, and, by means of a cord, a ball was drawn to the top to indicate "safety" or lowered to the ground to indicate "danger." At night an ordinary stable lantern was hooked on instead of the ball. M.4077.

905. Model of Grand Junction Railway signal, 1838. (Scale 1 : 16.) Made by Messrs. G. Cussons, Ltd., 1912.

This represents the form of signal used on the Grand Junction Railway, which was the first line to be properly furnished with fixed signals from its commencement.

The signal consisted of a perforated semi-circular board, fixed symmetrically on the top of an iron pillar which revolved in bearings attached to a short wooden post. The board turned towards the engine driver indicated "danger," and when turned on edge, "safety." A lamp with red and white glasses was fitted to the top of the pillar and turned with the board. This form of signal was also used on the Liverpool and Manchester Railway. M.4076.

906. Model of revolving disc signal. (Scale 1 : 16.) Made by Messrs. G. Cussons, Ltd., 1912.

This form of signal was introduced on the London and South Western Railway about 1840.

It consisted of a light circular iron frame covered with canvas or tin, but with a semi-circular aperture in it extending nearly to the outer edge. The disc was mounted on a central pivot fixed to a pillar, and was rotated by a cord fastened to its edge and passed round guide pulleys to an adjustable pulley near the bottom of the pillar. The signal was used to control two lines; if the closed part of the disc was turned to the left side, it indicated that the left-hand road was blocked; if the closed part was to the right, then the right-hand road was blocked. When the closed part was turned to the top both lines were blocked, and if the whole disc was turned with its edge to the driver it indicated that both lines were clear. For night use two lamps, with red and green glasses in each, were mounted on spindles on either side of the pillar. This signal was largely used to cover shunting operations, and a similar one, in which the disc did not rotate about its centre, but only turned with the pillar, was for a long time the standard distant signal on this line. M.4078.

907. Model of disc and cross-bar signal. (Scale 1 : 16.) Made in the Museum from information supplied by the Great Western Railway Co., 1912.

This represents the first form of signal designed to give a positive "clear" indication; it was introduced, in 1841, on the Great Western Railway, and was for many years the standard signal on that line.

It consisted of a pillar having a disc fixed to its upper end, while below, and at right angles to it, a cross-bar was attached. A lamp with red and white glasses was fitted below these, and the pillar was turned by hand in bearings fixed on a wooden post. The cross-bar, when turned to face the driver, indicated "danger" and the disc could not be seen; but when the bar was placed parallel with the line the disc came into view to indicate "line clear." In 1847 the plain bar was used as an "up line" signal, while the "down line" signals were distinguished by a pair of downward extensions at the ends of the cross-bar. At junctions, the branch line signals had double discs and cross-bars. M.4109.

908. Model of Gregory's semaphore signal, 1841. (Scale 1 : 16.) Made by Messrs. G. Cussons, Ltd., 1912.

This represents the first application of the semaphore to railway signalling; it was erected in 1841 by Sir C. H. Gregory at New Cross, on the London and Croydon Railway.

The signal consisted of a wooden post having a long slot at its upper end which accommodated two arms that were pivoted at the top, one arm serving for the down line and the other for the up line. The arm extended horizontally to the left indicated "danger"; when inclined downward at 45 deg., "caution"; and when lowered entirely within the post, "line clear." The arms were moved by wire ropes passing round pulleys on the arms and at the bottom of the post, the lower pulleys being turned by hand levers fixed to their spindles; quadrants and pins were used to hold the levers in the three positions. Lamps with red, green and white lenses were mounted on two vertical spindles attached to the post, and were rotated by handles at the bottom. Later on the ropes were replaced by rods and levers, and counterweights were added to return the signal to the danger position. The lamps were also arranged to be turned by the signal levers. M.4080.

909. Model of double disc signal, 1846. (Scale 1 : 16.) Made by Messrs. G. Cussons, Ltd., 1912.

In this form of signal two circular discs were mounted on a horizontal shaft carried in bearings fixed to the top of a post. It was used from about 1846 as a distant signal in distinction from the semaphore type, which was at first used on some lines as a "home" signal only.

The shaft was counterweighted so that the discs were normally vertical, indicating "danger"; they were turned horizontally, to indicate "safety," by a wire attached to an arm on the shaft and passing round a pulley at the foot of the post, from whence it was led to the signal-box. M.4079.

910. Model of semaphore signal, 1874. (Scale 1 : 16.) Made by Messrs. G. Cussons, Ltd., 1912.

This represents the ordinary semaphore signal in use in 1874. In it the up and down line arms were mounted on the same post, but the caution position had been abolished, so that the signal gave two indications only, the arm when horizontal indicating "danger" and when inclined at 45 deg., "line clear."

The arms were actuated through rods and levers by a hand lever moving over a quadrant at the foot of the post. A single lamp was hung on the post and it could be raised or lowered by a cord and winch; two spectacles, with red and green glasses, were fitted, one on each side of the lamp, below the signal arms, but moving with them. M.4081.

911. Model of home and distant signals. (Scale 1 : 16.) Made in the Museum, 1913.

This represents the standard form of signal used on the Great Eastern Railway. Distant signals are usually fixed at a distance of 1,000 yards in advance of the corresponding home signals, but with short block sections these signals may come near to or overlap the starting or home signals of the next section, in which cases they are fixed on the same post as, but 6 or 7 ft. below, the latter. With this arrangement, which is shown by the model, the distant signal is so controlled that it can only be lowered after the upper signal is lowered.

The signal arm is of cedar wood tapered towards the outer end and counterbalanced by the cast iron spectacle plate to which it is bolted. The arm is mounted on a spindle that passes through bearing plates bolted to the wooden post and has the back spectacle fitted to its rear end. The signal is

operated by a rod from a lever near the ground and the lamp is mounted behind the front spectacle on a bracket bolted to the post. The distant signal arm is distinguished from the other by having a V-notch cut at its outer end. A "drop off" controller is fitted for working the distant signal. There are the usual two counterweighted levers operated by wires from the signal-boxes, and the inner lever is directly connected with the upper signal arm; between these two levers is a third lever, which has one end connected with the distant signal arm, while the other end has a cross piece that rests on top of the main levers and is fitted with a counterweight sufficiently heavy to lower the distant arm, which it can only do when both the main levers have been pulled down by the two signalmen concerned. When either of the main levers is returned the distant signal returns to the danger position also. Access to the signals and lamps is obtained by means of an iron ladder fitted with two platforms. M.4243.

912. Model of centre pivot semaphore signal. (Scale 1 : 16.) Made in the Museum from information supplied by the Great Northern Railway Co., 1912.

This represents the form of signal adopted on the Great Northern Railway; it differs from the ordinary form in that the signal arm is pivoted about its centre, the pivot being fitted to a bracket projecting from the post.

The arm increases in thickness from the outer to the inner end, so that it goes to danger if its connections fail, and any accumulation of snow on the arm does not affect it. The spectacle plate is separate from the arm and is pivoted on the post at the same level; its weight helps to keep the wire taut so that a smaller counterweight can be used. The clear indication is given by turning the arm through 90 deg. to the vertical position, stops being fitted to limit the motion. A small white back light is provided, which is visible only when the signal is at danger, and the back spectacle is fitted with a purple glass which shows when the signal is off. The signal is operated in the usual way by a rod from a lower lever, to which a wire from the signal-box is attached. M.4143.

913. Model of ground disc signal. (Scale 1 : 16.) Made in the Museum, 1913.

This represents the form of dwarf signal used on the Midland Railway; such signals are generally used for sidings and crossovers.

A short wooden post has a bearing bracket fixed to it which supports a vertical pillar carrying a lamp with red and green lenses; a red disc for day use is fixed to the lamp round the red lens. The pillar is turned through an angle of 90 deg. by a slotted lever, fixed to its lower end, and a counterweighted bellcrank lever which is operated from the signal-box. M.4197.

914. Model of Stevens's switch indicator. (Scale 1 : 16.) Made by Messrs. G. Cussons, Ltd., 1912.

Before the general adoption of the interlocking of points and signals, indicators were used to show the position of the points and switches; the one represented, which was patented by Mr. J. J. Stevens in 1862, was that most used.

It consisted of a post carrying a V-shaped frame, within which was fitted an arm pivoted at the bottom and actuated by a rod which received its motion from the points themselves. The arm laid to right or left indicated which way the points were set. A lamp was placed below the arm, and spectacles with coloured glasses were attached to the arm in front of the lamp. White and green indicated the extreme positions of the arm, while a red glass in the middle would show if the points were not fully over. M.4082.

915. Drawing of Gregory's signal interlocking frame. (Scale 1 : 8.) Prepared in the Museum, 1912.

In the early days of railways, signalling was done by flags in the daytime and lamps by night, and, when fixed signals came to be substituted, they were operated by handles at the foot of the signal post. With increasing traffic this was found disadvantageous at junctions, or other places where several signals had to be attended to, and in 1843, Sir C. H. Gregory operated the signals at the Bricklayers' Arms junction, on the Croydon Railway, by chains, the ends of which were gathered together in a stirrup frame so that all could be worked from one spot. He also arranged the frame so that it was impossible to lower conflicting signals at the same time; but, although the switch levers were fixed on the same platform, they were quite independent of the signals.

The frame supported four vertically moving stirrups, to the upper ends of which the chains were attached and whence they were led to the signals by guide pulleys. Pendant links were fitted to the pillars between the stirrups, and the lower ends of the pair on each pillar were connected by another link considerably longer than the distance between their upper centres. By this arrangement the depression of one stirrup pushed the links sideways and prevented the lowering of the adjacent stirrups. M.4048.

916. Model of Chambers's interlocking frame, 1860. (Scale 1 : 4.) Made in the Museum, 1912.

In order to prevent accidents at railway junctions it was soon found necessary, as traffic increased, that the points and signals should be mechanically connected, so as to work in harmony and to prevent conflicting signals from being given. The first attempt to attain this object was made, in 1856, by Mr. J. Saxby, who connected together the point and signal levers so that they worked simultaneously; this model, however, represents the interlocking frame patented by Mr. A. Chambers in 1860, which was the first frame on the present system wherein each lever moves independently, but is controlled by the previous movement of the point or conflicting signal levers.

The signal wires are led to vertical rods mounted in a frame, each rod having a stirrup formed in it which is pressed down by the foot of the signalman when the signal is to be lowered, and is held in that position by a pin on one side engaging with the turned up end of a groove cut in the adjacent frame pillar. The point levers are mounted on horizontal shafts carried in bearings bolted to the back of the frame, and the point rods are connected with their lower ends. The signal stirrups are guided by their stems passing through holes in cross-bars at the middle and bottom of the frame, and slots are cut in the lower bar through which pass projections formed on two horizontal plates connected with the lower arms of the point levers. These projections when moved under the stirrups prevent them from being lowered, but when they are withdrawn, or present a hole under the stirrup, then the signal can be lowered. The frame is designed for a simple junction of a double line and the stops are so arranged that the main or branch signals cannot be lowered until the points have been moved into the correct positions, and no conflicting signals can be lowered together. M.4035.

917. Model of signal interlocking frame. (Scale 1 : 3.) Received 1908.

The value of point and signal interlocking having been demonstrated, many arrangements were invented for this purpose, and in 1870 Messrs. J. J., J. J. F., & W. A. Stevens patented the tappet interlocking mechanism, which has practically superseded all others. In this system the locking is performed by bolts or dies sliding in longitudinal channels, and engaging with notches formed in bars and tappets that are attached to the levers. The model shows a twelve-lever frame suitable for controlling a simple double-line junction, fitted with distant, home, and starting signals for the main and

branch lines, and with facing and trailing points for the branch. The levers are, however, reduced in length.

The frame consists of three standards connected by angles and bars, and the twelve levers are placed side by side and mounted on a shaft placed below the signal-box floor; the levers work through slotted quadrants bolted to the cross-bars, and are held at each end of their stroke by catch-plates and spring catches. In front of the levers, just below the quadrants, angle-irons forming three longitudinal channels are mounted, and their vertical flanges are cut away opposite the levers, to form guides for the tappets. The tappets are flat bars, forked at one end and pinned to the levers; the notches cut in their edges have one or both sides bevelled. The dies are small pieces of steel, placed between the tappets, and having their ends formed to fit the notches in them. When one tappet has to control another not adjacent to it, the dies are made in two pieces, connected together by thin plates that pass above or below the intermediate tappets and dies. Covers are fitted where necessary to prevent loose dies from rising. When a die is in engagement with a tappet, the lever belonging to it will be locked, unless there is a notch in another tappet opposite the other end of the die, which will allow it to slide in the channel when the lever is pulled over. The tappet into which the die has entered will then be locked if the first tappet, when over, prevents the die from returning. For instance, the distant signal lever, No. 1, cannot be moved until the home and starting signal levers, Nos. 2 and 3, have been pulled over, so as to present notches behind the two dies which lock it. When lever No. 1 is over, it backlocks No. 2, and No. 2 backlocks No. 3, so that the signals can only be taken off in the inverse order. The provision of starting signals in advance of the home signals, allows a train to be stopped at the end of one block section, while another train may follow it as far as the home signal. This arrangement, however, necessitates special locking in order to prevent the second train from proceeding before the first has left the section; this is effected by additional tappets on the home and starting signal levers, which cause the home signal lever to lock itself when pulled over once, so that it cannot be pulled over a second time until the starting signal has been lowered and again put back to danger. The facing points are fitted with a bolt connected with a train locking bar, and also with the signal box, so that the points cannot be moved while a train is passing over them. The interlocking gear provides that the point levers cannot be moved until the bolt is withdrawn, and no signals can be taken off until it is replaced. The setting of the points releases the corresponding signals and at the same time locks the conflicting ones. M.3575.

918. Audible fog signal. Presented by B. S. Barton, Esq., 1898.

The detonating signal, now generally used on railways during foggy weather, when the semaphore signals are invisible to the engine-drivers, was introduced by Mr. E. A. Cowper in 1841. It consists of a metal case containing gunpowder, and caps for exploding it: this is placed on the rail and secured by a leaden band soldered to the case and folded under the rail head. During fog, a man stationed at the signal post fixes the detonator on the rail when the signal is at danger, so that it will be exploded by a wheel as the engine passes over it. He removes the fog signal when the semaphore is lowered. M.3034.

919. Railway fog signaller. Lent by Messrs. Stanford & Co., 1898.

This apparatus for placing detonating signals upon the metals when, through fog, the signal arms or lamps are invisible, was patented in 1892 by Messrs. B. S. Barton and E. K. Stanford.

In the apparatus the detonators are secured to light carriers which fit on an arm that, by an independent rod from the signal cabin, can be swung

horizontally in such a way as to place and retain the detonator on the rail. The detonators are stored in a star-shaped rotating hopper, from which they are fed one at a time and fixed on the placing arm by mechanism actuated by the cabin rod. A detonator that is withdrawn before being exploded is returned to the box, although not into the hopper. An electrical signalling arrangement is added which indicates when the detonator has been correctly placed on the rail. The cover of the iron box, in which the apparatus is contained, has been removed. M.3034.

920. Diagrams of audible cab-signalling apparatus. Lent by the Great Western Railway Co., 1911.

This cab-signalling apparatus, patented by Messrs. C. M. Jacobs, R. J. Insell and others in 1905, and introduced on the Great Western Railway in 1906, is designed to supplement or to take the place of the distant semaphore signals. It is electrically worked, and gives a positive audible indication for both positions of the signal, a whistle being blown if the signal is at danger and a bell rung if the line is clear; it is also arranged that if anything fails the danger signal is given.

The system is in use on several branch lines, on single lines without semaphore distant signals, and on sections of the main line. M.3957.

921. Train-signalling instrument. Presented by H.M. Post Office, 1912.

This is one of the instruments supplied by Messrs. Cooke and Wheatstone to the London and Blackwall Railway in 1840, for the purpose of signalling from the intermediate stations to the termini, when the cables, by which that railway was then worked, were to be started or stopped. This was the first successful application of the electric telegraph to railway signalling.

The London and Blackwall Railway, built to connect London with the India Docks, was the first railway to enter the City. It was authorised in 1836, opened between Minories and Blackwall in July, 1840, and extended to Fenchurch Street in 1841. The line was double, about 3·5 miles long, and was built mainly on a brick arch viaduct; the gauge was originally 5 ft., but was afterwards reduced to 4·71 ft. As the railway ran through a densely populated district, and the loads were too great for the locomotives of the day, the engineers, Messrs. G. Stephenson and G. P. Bidder, decided to work the traffic by means of two reciprocating cables, the ends of which were wound on drums driven by stationary engines placed near the termini. There were ultimately seven intermediate stations, and a shuttle service was worked, on both lines, between Fenchurch Street and each of the five stations at the Blackwall end, and between Blackwall and each of the five stations at the London end. Each station had one or more carriages assigned to it, which worked between that station and the terminus only. The carriages were attached to the cable by grips while it was stationary, and when all were attached the engine at the forward end was started, while the engine at the rear paid out the cable under the control of a brake. The carriages were thus drawn forward, and as each approached its destination it was slipped from the cable or train and stopped by its brakes. There was thus a non-stop service between each station and its appropriate terminus, but no service between intermediate stations.

Such a system could not have been worked successfully without the aid of the electric telegraph. Each terminus was provided with a number of single-needle instruments, one for each station, these being arranged in a common frame; the one shown was situated at Blackwall, and communicated with the stations at Poplar, West India Dock, Limehouse, Stepney, and Minories. The intermediate stations each had one single-needle instrument. When the carriages at Blackwall and the adjacent stations were ready for starting, and properly attached to the cable, the signal "ready" was sent from each station to Blackwall; when all the needles indicated "ready," a signal was sent to

Minories to start the engine at that end. As the carriages arrived at their several destinations, the needles of the instrument at Minories were put over to the "stop" position by the signalmen at those stations; when all the needles were in that position the engine was stopped. The reverse journey was worked in the same way.

Cable traction was in operation until about 1849, when locomotives were substituted on the line being connected with other systems. The railway was leased to the Great Eastern Railway Co. in 1866. M.2184.

922. Block-signalling telegraph instruments. Presented by H.M. Post Office, 1912.

The electric telegraph was first applied to the working of railway traffic by Sir W. F. Cooke in 1837, ordinary speaking instruments being used. In 1842 he devised a scheme in which the line was to be divided into sections, each governed by its own telegraph, and into which no second train should be allowed to enter until the first one had been signalled clear of it. This arrangement, now known as the "block system," was first tried on the Norfolk Railway, a single line between Brandon, Norwich, and Yarmouth, in 1844–5; although it considerably reduced the possibility of collision, its use was not made compulsory everywhere until 1889. The length of the sections varies inversely with the amount of traffic to be dealt with.

Cooke's original idea was that the state of the whole line should be known at all the stations on it, and for this purpose each station was to be provided with as many single-needle instruments as there were stations. This arrangement would have been impracticable on a line with a large number of stations, so that actually such a line was divided into sections having five or six stations in each.

The large instrument shown was used at one of the termini of the Brandon and Norwich section of the Norfolk Railway in 1845; it consists of five single-needle instruments, mounted in a common casing and provided with drop handles for transmitting signals. One of the needles was used for both terminal stations, but at the intermediate stations six needles were required. The central needle has a code marked on its face, and it was used also as a speaking instrument for transmitting train orders when necessary; a bell was used to call attention. A movement of a needle to the left indicated an up train, while a movement to the right indicated a down train.

On an up train being ready to start from Brandon, the signalman there would turn the handle of his Brandon needle and so put all the other Brandon needles to indicate "up train." The signalman at the next station, Thetford, if he could accept the train, would signal that his section was clear by putting the handle of his instrument over so that all the Thetford needles indicated "up train." The train could then start, and when it had left Brandon the Brandon needles were put back to the normal position. This process would be repeated as the train progressed, and the needles would indicate the position of all trains on the line.

The multiple instrument system was soon found unnecessary, and was replaced by a simpler system in which the signalling took place from station to station as now. The single-needle instrument shown was one employed at Trowse station, which was the Norwich terminus when the line was opened in July, 1845. M.2186 and 2190.

923. Early train indicator. Presented by H.M. Post Office, 1912.

This is an instrument, used on the South Eastern Railway about 1847, probably for indicating the position of a train when passing along the line. Its mechanism was patented by Messrs. Cooke and Wheatstone in 1845.

Its wooden casing has a large dial, the circumference of which is divided into a number of sections each bearing the name of a station on the line. A pointer, which moves round the dial, is driven intermittently by the mechanism

of a clockwork alarm bell normally held at rest by a catch that engages with a revolving bell hammer. An electro-magnet is fitted to it, and when this is energised by the closing of a switch, its armature releases the catch and allows the hammer to make one revolution, thus striking the bell and causing the pointer to advance one section. Successive strokes of the armature will each advance the pointer one section. M.2188.

924. Clark's block-signalling telegraph instrument. Presented by H.M. Post Office, 1912.

Cooke's original signalling system was improved by Mr. E. Clark, and the instrument shown is one designed by him in 1854 for use on the London and North Western Railway. It has two needles, which indicate by their left or right positions, "train on line" or "line clear;" the normal vertical position, which is maintained when anything goes wrong with the instruments or circuits, indicates "line blocked." The needles are controlled by drop handles, and information is conveyed from one signalman to the next by temporary movements of the needle, according to a code of beats. The needle is then held over permanently in either position, to indicate the state of the section, by securing the handle by means of a peg that engages with the sides of a stop below it. A bell on an independent circuit was used to attract attention. In modern practice, however, a bell alone is used for conveying information, and the needle is used solely to indicate the state of the section and is controlled by the signalman at the forward end of it. M.2189.

925. Electrical semaphore. Presented by H.M. Post Office, 1912.

This is a portion of the railway block-signalling apparatus patented by Sir W. H. Preece in 1862; it was intended to replace the ordinary needle instrument which indicates to the signalman the state of the section ahead, the idea being that the indoor indicator should assimilate to the outdoor signals used. It was first adopted on the London and South Western Railway.

The instrument consists of a miniature semaphore, the arm of which is raised or lowered by a lever attached to the polarised armature of an electro-magnet. As the current is intermittent, a non-polarised armature, attracted by the same magnet, is used to operate a catch that holds the arm at the position in which it was placed by the last current sent. M.2169.

926. Railway signal bell. Presented by H.M. Post Office, 1912.

This is an alarm bell which was situated at the entrance to a tunnel and rang continuously while a train was situated therein.

The bell hammer is driven by clockwork, and, while normally held at rest, is released by the armature of an electro-magnet when a current is passed round its coils. The speed of the bell is regulated by a flier, and it ceases to ring when the circuit is broken. M.2161a.

927. Block telegraph instruments. Presented by the Director of the Imperial Institute, 1909.

These instruments, which were used on the Victorian railways in 1892, are of the form patented by Messrs. G. K. Winter and J. Craik in 1880 and 1885. They are electrically interlocked with the outdoor signals, which cannot be lowered until they are unlocked by the combined action of the signalmen at both ends of the section. The ordinary instrument has two dials, the needles of which can take up either of two positions, indicating "line cleared" or "train on line;" one dial refers to trains coming from the next box and the

other to trains going to it. The needles and bells are operated by relay circuits. By the addition of a single connection the instrument may be used for single line working; it is then impossible to signal trains in both directions at once. M.3598.

928. Distant signal repeater. Presented by the Director of the Imperial Institute, 1909.

This is a portion of the signalling apparatus used on the Victorian railways in 1892. It indicates to the signalman the movements of his distant signal, which may be out of sight. It consists of a miniature semaphore, which is operated by an electro-magnet with a polarised armature, the current for which is reversed by a commutator on the axis of the signal arm. A model of the distant signal is shown. M.3600.

929. Automatic indicator and bell. Presented by the Director of the Imperial Institute, 1909.

These instruments were used on the Victorian railways in 1892.

The automatic indicator shows the signalman whether the section is occupied or not. It consists of an indicating shutter attached to the polarised armature of an electro-magnet. It is operated through a relay which reverses the current through the magnet coils when a track circuit is closed by the wheels of a train.

The automatic bell is caused to ring by the wheels closing a circuit as the train passes a certain point on the line. A model of the track shows the electrical connections for both instruments. M.3599.

930. Platform indicator. Presented by the Director of the Imperial Institute, 1909.

This is an electrically operated indicator used on the Victorian railways in 1892. It shows at which of two platforms a train is due, and consists of a roller rotated by chains wound on its axle and attached to the armatures of two electro-magnets. M.3601.

931. Photographs of automatic and power signalling appliances. Presented by The MacKenzie, Holland and Westinghouse Power Signal Co., Ltd. 1914.

Automatic signals, although not extensively used on ordinary railways in this country, are a necessity on such lines as the London underground railways, where the trains are frequent and the block sections short. The power needed for the signals is also made use of for operating the points, etc. These photographs show some of the appliances used in the all-electric system as applied on the Metropolitan Railway.

In this system the signals are controlled by alternating current track circuits which cannot be deranged by extraneous currents. The trains operate the signals through relays, which are shunted when the opposite rails are connected by the wheels and axles, thereby opening the direct current circuits which operate the signals. The signals stand normally "clear," and are put to "danger" when the train has passed; they also go to "danger" if any part of the circuits or mechanism fails.

Two kinds of signal are used, an upper quadrant semaphore for the open parts of the line, and a lamp signal for the tunnels. The arm of the former is raised through an angle of 60 deg., to the "off" position, by an electric motor, instead of being lowered as in the ordinary form; this arrangement allows the arm to return to "danger" by gravity without the aid of counterweights. The lamp signal consists of two electric lamps placed behind

coloured lenses; one or other of these is lighted by the action of the relay. By placing a hood in front of the lamps, these signals can be used in daylight.

At junctions the points, bolts, and locking bars are operated by electric motors controlled by an electric interlocking frame, having miniature levers and the usual mechanical tappet locking. The stroke of a lever cannot be completed until a return indication has been received from the point and bolt detectors showing that the movement has been properly completed. The signal levers are similarly controlled by the track circuits, while the signals are automatically put to danger by the trains. The signal box is furnished with an illuminated diagram showing the state of the track circuits under its control, the occupied sections being dark, while the unoccupied sections are illuminated.

To prevent trains from overrunning the signals, train stops are provided which work in unison with the signals. An arm placed beside the rail, rises when the signal is at danger, so that if a train passes the signal this arm opens a cock on the engine brakepipe and applies the brakes. In order to inform the signalman at a junction what train is approaching him, automatic train describers are used; these store up all the trains which have entered the space between the boxes concerned and deliver them one by one at an annunciator. A similar arrangement is used for indicating, at each station, the destinations of the approaching trains. Inv.1914—905 to 915.

LAND TRANSPORT.—III.

Rail and Tramway Vehicles and their Fittings, including Brakes, etc.

The passenger traffic which unexpectedly developed on the first railway was accommodated by placing coach bodies on wagon under-frames; and, following the stage coach arrangement, seats were booked before starting, luggage was carried on the top of the vehicle, and frequently a guard was seated beside it outside (*see* Nos. 935 & 941). As traffic increased the form of passenger vehicle thus introduced was adhered to except that additional accommodation was obtained by providing more compartments in the greater length possible on a railway, and this is the construction still generally followed here; in America, however, the railway car appears to have been developed from the steamer saloon, and is characterised by the vestibule construction. In the stage coach traffic the inside passengers, representing the first-class, paid the highest fare, the outside passengers or second-class being taken at a reduced rate, while the poor could not avail themselves of the service. With the early railways first-class passengers were originally provided for, then a cheaper accommodation was added for the second, while the third class, taken at a rate established by Parliament, were most unwillingly accommodated by the companies who, for many years, displayed considerable ingenuity in attempting to discourage cheap travelling. Some of the earliest third-class vehicles consisted of open wagons without seats, and improvement was so slow that even in 1845 many coaches had neither windows nor lamps; about 1870, however, it began to be generally realised that it was upon the popular traffic that the receipts depended, the amount of dead weight carried and the capital invested in superior coaches being out of proportion to the paying load conveyed by them even at the higher rate charged. In carriage construction the increased length and capacity of the vehicles have been followed by the use of rolled steel beams in place of wood for the under-frames, and by the use of bogies instead of a long rigid wheel base. The buffers originally used were simply pads strengthened by metal bands, while the carriages were hooked together loosely like goods wagons, the present system of close coupling being introduced by Mr. Henry Booth, who, in 1836, patented the now general right and left threaded screw coupling; automatic couplings by which the vehicles of a train can be connected together or detached without a man having to pass between them have been very generally adopted in America and the matter has received much attention in England, where, however, the double buffers used in place of the American central buffer add to the difficulty of the problem.

Railway Brakes.—For carrying traffic safely at a high speed the power of rapidly arresting the motion of a train is so essential that on almost all lines the early hand brakes, applied

to a few vehicles only, have been replaced by those simultaneously applied to all the wheels of the train so as to secure the maximum amount of retarding action. Chains or shafting have been used to transmit the power to these continuous brakes, but fluid pressure, chiefly air, is now the means generally employed; such brakes stop a train moving at 50 miles per hour within a distance of 1,000 to 1,500 ft., depending upon the state of the rails.

Rolling Stock.

932. Model of timber railway and quarry truck. (Scale 1 : 10.) Made in the Museum, 1904.

The models shown were made from the drawings published by Desaguliers in 1734 as representing the arrangements used by Ralph Allen to convey stone from his quarries to the River Avon, near Bath, which are described as "a great improvement on some carriages and waggon-ways made use of at the coal mines near Newcastle." The quarries were situated 1·5 miles from the river and 500 ft. above its level, the line thus having an average gradient of 1 in 16.

The wagon-way consisted of rectangular rails of oak laid along the ground and probably connected by cross ties, covered with ballast to prevent damage from the horses' feet; the rails were 5 in. wide by 6 in. deep, and were laid to an inside gauge of 3·75 ft.

The truck was carried on four cast-iron wheels having deep flanges on the inner edge to prevent them from leaving the rails, while the axles revolved in brass bearings secured to transverse beams below the floor; one wheel was fixed on each axle, the other being free to revolve independently. The loaded truck descended by gravitation and was controlled by a man walking behind it, who could retard the four wheels separately. This was accomplished at each rear wheel by a wooden brake block, pressed on to the rim by a lever which was drawn down by a chain wound on a drum, while the drum was rotated by a handspike and retained by a ratchet wheel; the front wheels were braked by actually locking them, two iron bolts being provided which could be thrust between their spokes by means of levers and rods operated from the rear of the truck.

The return journey was made by two horses, the brake levers being removed and placed inside the truck; the sides of the truck were also removable. The truck measured 12 ft. long by 3·5 ft. wide and had a wheel base of 6 ft. The wheels were 19 in. diam., 6·5 in. wide on the tread, and had flanges 3 in. wide and 1 in. thick; the axles were 3 in. diam. The load carried was four tons, and the cost of each truck was 30*l*. M.3359.

933. Model of railway carriage (1825). (Scale 1 : 6.) Lent by the Lancashire and Yorkshire Railway Co., 1907.

This model represents the "Experiment," the first passenger carriage ever used on a railway. It was constructed in 1825 for use on the Stockton and Darlington Railway, a line which had then been recently constructed for goods traffic (*see* No. 189).

The carriage consisted of a body similar to that of an ordinary stage coach, supported on two longitudinal beams, the ends of which served as buffers. It was carried on four wheels 34 in. diam., with a wheel base of 51 in., the axles running in fixed bearings without springs. The carriage had an overall length of 12 ft., a width of 5·25 ft., and a height from the rails of 7 ft.

A copy of an original handbill (adjacent) shows that the "Experiment" commenced running daily on the 10th of October, 1825, the fare charged between Stockton and Darlington being one shilling. M.2735.

934. Views on the Garnkirk and Glasgow Railway. Presented by R. B. Prosser, Esq., 1895, and C. E. & C. Stretton, Esqs., 1900.

This series of views was drawn by Mr. D. O. Hill, and published at Edinburgh in January, 1831.

The railway was intended as a mineral line and was 8·25 miles in length. George Stephenson was the engineer, and the line, which cost 40,000*l.* only, was opened for traffic in 1831. The Glasgow terminus was on the banks of the Forth and Clyde and Monkland canals, and is now the St. Rollox goods station, which is close to the Buchanan Street station of the Caledonian Railway, of whose system this line now forms part. The other terminus was at Cargill Colliery, near Gartsherrie Bridge, where the line joined the Monkland and Kirkintilloch Railway.

The locomotives shown in the views are the "St. Rollox," a four-wheeled engine, with inside cylinders 11 in. diam. by 16 in. stroke, and single drivers 4·5 ft. diam.; and the "George Stephenson," a four-coupled engine of the same dimensions, which opened the line. The carriages are chiefly open-topped four-wheeled wagons with hand rails. The road was laid with fish-bellied wrought-iron rails on stone blocks. M.2755 and 3096.

935. Prints of early rolling-stock of the Liverpool and Manchester Railway. Received 1895–6.

These aquatints, published in 1833–4, record with considerable detail and accuracy the arrangement of our early trains.

The first class carriages shown are obvious adaptations of the stage coach design, and have distinguishing names such as "Times," "Traveller," etc., just as when used on the road. The first-class train has a guard on the box-seat of the foremost coach, and another on a similar seat on the hindmost. Luggage is carried on the roofs, and an open truck is provided in which an ordinary private carriage is conveyed, with its occupants in it. The second-class carriages have low sides and a light awning supported considerably above them on uprights, while bench seats were fitted. The third class carriages were simply open wagons without seats, but provided with holes in the floor to carry off the rain-water that collected. Cattle, sheep and pigs are shown carried in trucks with open railed sides, those for sheep being two-storied; the horse truck closely resembles those still in use. The goods trucks are short four-wheeled vehicles without sides, while for conveying timber two trucks are used, the requisite length being obtained by leaving considerable space between the buffer-beams.

One of the engines shown is of the "Rocket" type, and is called the "North Star"; it had outside cylinders 11 in. diam. by 16 in. stroke, with single drivers 60 in. diam. The tender is a four-wheeled truck, containing coal and a large water-barrel. The other engine, "Jupiter," was of the "Planet" class, with cylinders 11 in. diam. by 16 in. stroke, and 5 ft. drivers, but as it is shown with four equal wheels, it is probable that the engine represents one of the "Samson" class with cylinders 14 in. diam. by 16 in. stroke, and four-coupled wheels 54 in. diam., but that the artist has omitted the coupling-rods. Its tender has a rectangular iron tank instead of the earlier wooden barrel. M.2745.

936. Photographs of early railway carriages. Presented by the London and South Western Railway Co., 1896.

These vehicles, which are still in existence (*see* Nos. 938 and 942) were used on the Bodmin and Wadebridge Railway, Cornwall, at, or shortly after, its opening in 1834, and remained the only passenger carriages of the line till 1889, when the railway, which had remained isolated, was modernised.

The Bodmin and Wadebridge Railway was a mineral line, about 15 miles in total length and of standard gauge, built in 1834 as a private undertaking at a total cost of 35,000*l.* It was financially unsuccessful and, although purchased by the London and South Western Railway in 1846, remained in its primitive state till 1889, when the Great Western connected with it at Bodmin; in 1896 the London and South Western joined it to their system at Wadebridge. Till its conversion to modern arrangements, the line was worked by two six-wheeled coupled locomotives, one of which was in reserve, and a number of hopper wagons together with the four passenger vehicles shown in these views; the passenger traffic was, however, confined to the 7·5 miles of line between Bodmin and Wadebridge.

The composite carriage has a central first-class compartment and a second-class compartment at each end, all upholstered in blue cloth and lighted by two lamps in the roof, together with the side windows; each compartment is 4·5 ft. long, 6 ft. wide, and 5·75 ft. high, while the height from the rails to the top of the roof is 8·4 ft. This carriage is now preserved at Waterloo Station.

The second-class carriage consists of one compartment, 10 ft. long which seats sixteen persons, while the two third-class carriages are open trucks with seats and side doors. The wheels are of cast iron 25 in. diam. and support the vehicles by springs; spring draw-bars are fitted, but the buffers are formed of stuffed leather pads, or else of solid wood, and the coupling was performed by slack chains only.

In the frame is also a portion of an ordnance map showing the line, together with some other photographs of the rolling-stock. Further particulars of the permanent way are given under No. 828. M.2942.

937. View on the Bodmin and Wadebridge Railway. Lent by W. M. Acworth, Esq., 1909.

This reproduction of an engraving representing the opening of the above railway on September 30th, 1834 (*see* No. 828 and No. 936), shows a train of 21 wagons and one passenger coach, drawn by the locomotive "Camel," which was built by the Neath Abbey Iron Co. The engine had six-coupled wheels 46 in. diam. and vertical inverted cylinders 10·5 in. diam. by 24 in. stroke. The piston-rods were guided by parallel motions, and drove the leading axle by means of bellcrank levers and connecting rods. The boiler was cylindrical and had an internal flue, containing the grate, extending for about one-half of its length, and tubes from thence to the front end. The steam pressure was 50 lb. per sq. in., and a feed-water heater was fitted. The weight of the engine in working order was 12·25 tons; the tender carried 370 gal. of water and one ton of fuel, and with these it weighed 5·5 tons. The cost of the engine and tender was 725*l.* The larger wagons shown, which were for coal and sand, had wheels 3 ft. diam., weighed 2 tons, and cost 30*l.* each. The small ore wagons had wheels 22 in. diam., weighed 30 cwt., and cost 13*l.* each. M.3687.

938. Early railway carriage. (Scale 1 : 8.) Made by Messrs. Braun & Co. from information supplied by the London and South Western Railway Co., 1913.

This represents a second-class carriage built for the Bodmin and Wadebridge Railway about 1837, and used on that line until 1886 (*see* No. 936).

The carriage is a box-like vehicle having two compartments with transverse seats holding 16 persons. The body is 10 ft. long, 6·42 ft. wide, and 5·87 ft. high at the middle; it is framed in oak with pine panels, while lights are provided in the doors only. The seats are of plain wood, and a small oil lamp is placed at the centre of the roof. The underframe is of oak, securely stayed and bolted, and is supported on four cast-iron wheels with wrought-iron tires 25 in. diam. The horn plates are stayed to the frame, and the spring ends work between guides which have inclined slots to accommodate the spring pins. The buffers are of solid wood with iron bands round their outer ends.

A loose chain at one end and a hook at the other end are provided for coupling. Two footboards are fitted at each side. The wheel base is 6·33 ft., and the carriage weighs 2·27 tons.

The original carriage is preserved at Kingston-on-Thames Station.

M.4202.

939. Photograph of early railway carriage. Presented by the Dublin and South Eastern Railway Co., 1907.

This carriage was built in 1837 for the passenger traffic on the Dublin and Kingstown Railway, and was used occasionally until 1894. The line opened in 1834 was about 7 miles long, and was the first railway opened in Ireland; it was originally laid to the 4·7 ft. gauge, but this was altered to 5·25 ft. in 1854–5. The line now forms part of the Dublin and South Eastern Railway system. The carriage was for second-class passengers and has four compartments, three of them holding eight persons and the other one only four. It has a roof supported on iron pillars. The ends are closed but the sides are open. Loose cushions were provided for the seats. The carriage body is 17·2 ft. long and 6·7 ft. wide; it is mounted on four wheels 41 in. diam. with a wheel base of 10·5 ft. Side buffers are now fitted, but when built central buffers were used. The carriage is shown standing on some of the original rails; these were of wrought iron, bull-headed, and weighed 40 lb. per yd. when new. They were keyed into cast-iron chairs secured to granite blocks.

M.3524.

940. Photograph of passenger carriage of 1838. Presented by the South Eastern Railway Co., 1894.

This composite carriage was built in 1838, and used by the Duke of Wellington for his journeys on the Canterbury and Whitstable, now part of the South Eastern and Chatham, Railway.

In this carriage the central compartment is first class, the other two being second, and in the general arrangement some resemblance to a stage coach has been retained. The dimensions are: Length of body, 14·75 ft.; width of body outside, 6·7 ft.; length of wheel base, 8·125 ft. M.2728.

941. Models of railway passenger carriages, 1839. (Scale 1 : 8.) Lent by the Lancashire and Yorkshire Railway Co., 1907.

These models represent the second and third class coaches in use on the Manchester and Leeds Railway in 1839. They were four-wheeled vehicles supported on springs, and had a peculiar arrangement of elastic buffer.

The second class carriage was covered, had three compartments with glazed windows and half doors, while shutters were provided for closing the upper half of the doorway. A seat for the guard was placed on the roof at each end. The carriage body was 13 ft. long, 6·83 ft. wide, and 5·66 ft. high.

The third class carriage was an open truck with sides 4 ft. high surmounted by a hand rail, and having two doors at each side. No seats were provided, but holes in the floor were arranged to carry off rain-water. The body was 16·75 ft. long and 7 ft. wide.

The coaches had wheels 37 in. diam. with a wheel base of 8 ft.; they were coupled by chains. The solid buffer-heads were mounted on a separate beam supported by the main frames and behind this beam was placed a long transverse spring secured to the end of the underframe. M.2735.

942. Early railway carriage. (Scale 1 : 8.) Made by Messrs. Braun & Co., from information supplied by the London and South Western Railway Co., 1913.

This represents a third class carriage built for the Bodmin and Wadebridge Railway about 1840, and used on that line until 1886 (*see* No. 936).

Third class carriages were first introduced about 1838, and while some few lines used seatless trucks (*see* No. 941), the majority provided seated, open carriages resembling the one shown. The earliest second class carriages were of this type also, but by 1833 these were improved by the addition of a canopy roof.

The carriage body is 15 ft. long by 6·4 ft. wide, and is divided into three transverse seated compartments each holding eight passengers. It is framed in oak and has pine panels, the seats and backs being plain wood; the walls are secured to the floor by numerous iron knees. The underframe is of oak, securely stayed and bolted, and is carried on four cast-iron wheels having wrought iron tires 25 in. diam. The horn plates at each side are stayed together and to the frame by round iron bars, and the spring ends have the necessary freedom given by their pins moving in inclined slots formed in side guide plates. The buffers are of solid wood banded with iron, while a draw-hook is provided at one end and a coupling chain at the other. Two footboards are fitted at each side. The wheel base is 6·75 ft., and the carriage weighs 2·91 tons. M.4203.

943. Views on the Metropolitan Railway, 1863. Lent by the Metropolitan Railway Co., 1908.

These lithographs show two views on the Metropolitan Railway, the first portion of which, that between Bishop's Road and Farringdon Street, was opened in January, 1863. The line was about four miles long, partly in tunnel and partly in open cutting; it was designed for broad gauge traffic, and was originally worked by Great Western Railway locomotives of both broad and narrow gauge, three rails being provided as shown.

One view shows the junction beneath Praed Street of the lines leading to Praed Street and Bishop's Road stations; the two brick tunnels are here connected by a bell-mouthed tunnel formed of brick abutment walls surmounted by iron arch ribs of varying span. The broad gauge locomotive "Hornet" shown, was built by the Vulcan Foundry Co., in 1862, to the designs of Sir D. Gooch; it was a four-coupled outside cylinder tank engine, with cylinders 16 in. diam. by 24 in. stroke, and driving wheels 72 in. diam. Arrangements were made for turning the exhaust steam into the water tank.

The other view shows Baker Street station; here the ordinary tunnels are of brick 29 in. thick, with a width of 28·5 ft. and a height of 17 ft. above the rails; at the station, vertical walls behind the platforms are connected by a brick arch of 48 ft. span, and light is admitted through a number of inclined openings formed through the side walls. M.3578.

944. Models of Indian railway carriages. (Scale 1 : 8.) Presented by the Bombay, Baroda and Central India Railway Co., 1883.

These illustrate the third-class accommodation provided for the poorer natives of Hindostan; the carriages are double storied, and have four rows of longitudinal seats.

In the earlier type, access to the upper story is gained by "monkey boards" at either end of the carriage, the four doors serving for both stories; ventilation is effected by louvres or sun blinds, and the accommodation is for 110 passengers. In the later type the upper story is independent of the lower one, being reached by means of two doors and an internal stair in the centre and external stairs at either end of the carriage; ventilation is effected by wire gauze screens, and only eighty-eight passengers are carried. The gauge is 5·5 ft.; diam. of wheels 3·5 ft.; height above rail 13·1 ft., and the outside breadth of coaches 8·75 ft. The length of the earlier coach, over buffer beams, is 22 ft., and of the later 24·2 ft.; the wheel base of the former is 11 ft. and of the latter 12 ft. The vehicles are built entirely of teak, with double roofs covered with painted canvas. M.2771.

945. Models of cattle trucks. (Scales 1 : 6 and 1 : 12.) Presented by Alfred Welch, Esq., 1895.

The larger scale model represents an ordinary narrow gauge cattle truck fitted with arrangements for refreshing the cattle *en route*, as introduced by Mr. Welch in 1869. Transverse sliding doors are also provided to separate the cattle or to permit the use of the truck, or a portion thereof, for merchandise. A rack is provided at one end of the truck for holding hay, which can be supplied through sliding doors; or the food may be placed in overhead racks supplied through similar doors on the roof, as shown at the other end of the model. For watering the cattle, troughs are provided outside the truck, so preserving an unobstructed interior. Lifting or turning covers fitted to these troughs prevent their being fouled when not in use. The drinking water is contained in an overhead cistern intended to be filled from the engine water crane, and small pipes are provided to distribute the water to the various troughs. After watering the cattle at a siding it is intended that any water remaining should be run off.

The two smaller scale complete models represent trucks intended for use on the broad gauge. The feeding and watering arrangements are similar to the above, but are arranged transversely at the ends or at the middle of the truck. The trucks are divided into separate stalls formed by sliding partitions. By the provision of double doors on each side the cattle can be placed in, and removed from, their respective compartments without any "backing," a movement that is difficult of execution with frightened animals.

The partial model shows a modified form of sliding partition and double doors, arranged to dispense with "backing." M.2764.

946. Model of cattle truck with radiating axles. (Scale 1 : 8.) Presented by J. Cleminson, Esq., 1880.

This truck is fitted with the arrangement patented by Mr. Cleminson in 1876 for facilitating the passage of railway carriages round curves.

The truck has three axles, of which the middle one is capable of longitudinal movement, while the other two can swivel. The outer axles are so connected with the middle one that the sliding motion of the central axle causes the others to swivel and place themselves radial to the curve being traversed. The truck shown thus fitted has four compartments, each carrying three beasts for which troughs and racks are provided. M.1478.

947. Model of double hopper coal wagon. (Scale 1 : 16.) Lent by Messrs. Sheffield and Twinberrow, 1905.

This represents a large steel wagon of the form proposed and patented by Messrs. G. H. Sheffield and J. D. Twinberrow in 1898–9.

The use of such wagons is estimated to increase the ratio of paying load to gross load and the earning power of a train of given weight by about 20 per cent., at the same time reducing the length of the train. There are, however, some objections to their general use, chiefly in connection with the handling of goods and the alteration required in terminal structures, but high capacity wagons of various types are now being used on several railways particularly for mineral traffic.

The wagon is formed as a double hopper with horizontal sliding doors and is carried on two four-wheeled bogies. The sides are in the form of deep plate girders with angle-iron booms, tapered at the ends and attached to the headstocks. These serve as the main frames, being stiffened and tied together by the ends of the hoppers and also by transverse bulb bars at the top, while a stiff transom is built up over the centre of each bogie. There is also a hollow longitudinal tie which accommodates the draw-bar. The hopper doors are mounted on rollers running on angles forming a light framework which supports the hand gearing for operating them. The bogies have pressed steel frames and wheels 3 ft. diam. with a wheel base of 5 ft., the axles being fitted with helical springs. They have no central pivot, but

the load is carried by four semi-elliptical springs attached to the wagon body and bedded on bearing surfaces formed on the bogie frames. Their motion is controlled by four horizontal spring links, one at each corner, passing through lugs on the wagon and bogie frames. The buffers are arranged so as to equalise the pressures when passing round curves. The two stems pass through the headstock and are united by two cross beams, forming a frame which is pivoted just within the headstock; tension and compression springs are fitted to the inner cross beam, and the two headstocks are connected by a draw-bar to which the compression springs are attached. The buffers are constructed to act as automatic couplings, each being provided with a pair of hinged arms which embrace the corresponding buffers of the next wagon. The arms have short backward extensions which are held outward by two lugs projecting from a central boss, which is fixed to a movable spindle normally held by a spring so as to project from the face of the buffer and at the same time to release the arms. When one buffer head comes into contact with another, the arms embrace it, and the spindle is pushed in so locking them. The spindles can be rotated by a hand rod from either side to release the couplings.

The wagon is 42 ft. long, 8 ft. wide, and 9 ft. high, holds 36 tons of coal and has a tare weight of 14 tons; the load on each axle is 12·5 tons. The bogie centres are 32 ft. apart and the total wheel base is 37 ft.

Wagons of this form, holding 40 tons of coal, but without the automatic couplings, are in use on the North Eastern Railway. M.3389.

948. Model of ten-ton wagon. (Scale 1 : 8.) Lent by the Great Western Railway Co., 1908.

This represents a type of wagon used on the Great Western Railway; it is built entirely of steel and is fitted with the form of either-side brake patented by Messrs. W. Dean and G. J. Churchward in 1902.

The wagon underframe is built up of steel channel and angle bars, and the side and end plates are secured to it by angles and vertical posts; there is a hinged door at the middle of each side. The buffer stems engage with the ends of transverse springs, the buckles of which form links in the draw-bar. The brake gear consists of the usual pair of brake blocks on one side of the wagon, suspended by links and connected by hinged rods with short levers on the brake shaft. The brake shaft has a vertical lever on it, and a longitudinal motion of the end of this applies the brakes, a spring pulling in the opposite direction tending to keep them off the wheels. The gear for working the brakes from either side consists of a pair of transverse shafts carried in bearings below the frame, one at each end of the wagon, and each having a short hand lever fixed on one end of it; these two shafts are coupled together by levers and rods, and one of them carries a loose ratchet toothed sector, a point on which is connected with the brake lever by two rods and an intermediate lever for increasing the power. Fixed to the shaft by the side of the sector is an upward projecting lever that engages with a lug on the sector so as to turn it and apply the brakes when either of the hand levers is depressed. The brakes are held on by a spring pawl engaging with the teeth of the sector, but this is knocked off by the top end of the lever when the hand levers are raised to release the brakes. The brake blocks have lugs on them embracing the wheel flanges, and safety slings are fitted to the brake rods to prevent them falling to the ground if any part should fail.

The wagon runs on four wheels 36·5 in. diam., with a wheel base of 9 ft., and has an overall length of 19 ft.; its tare weight is 5·4 tons. In the model the floor plates are removable in order to show the construction of the framework. M.3537.

949. Models of carriage and wagon bogies. (Scale 1 : 8.) Lent by the Leeds Forge Company, 1901.

The employment of long railway carriages and wagons was only rendered possible by the adoption of the bogie truck, upon which the two ends of the

vehicle are supported by swivel connections, which reduce the rigid wheel base to that of the bogie, so that it is even less than that of the short four-wheeled trucks formerly invariably used.

The models represent two model bogies, manufactured upon the system patented by Mr. Samson Fox in 1885–96, in which the framework is made up of steel plate pressed, while hot, into trough-like forms, which give the desired strength and the means of attachment without the use of angle-iron or much riveting. In this way it is stated that an underframe is made with one-fourth the number of pieces and one-third of the rivets that are required in a similar frame of the usual channel and angle-iron construction; the consequent reduction in weight is such that coal wagons carrying 30 tons have been built of a tare weight of 12·8 tons.

The larger model represents a standard carriage bogie for a line of 5·5 ft. gauge. Each end of the carriage underframe is carried on a bolster by a central swivel plate and side bearings; the bolster is supported by six helical springs, on a beam which is suspended from the bogie frame, so that it can swing transversely; the bogie frame itself is suspended from the axle boxes by plate springs and end washers of rubber.

The smaller model shows a wagon bogie for the standard gauge of 4·7 ft. Each end of the wagon underframe is supported by bearing plates on the side frames of the bogie, and by a central pivot fitting into a fixed plate on the transoms; the weight of the bogie is transmitted to the tops of the axle boxes by plate springs, whose ends are held by lugs fixed to the frames. M.3200.

950. Model of gyrostatic monorail car. (Scale 1 : 8.) Lent by Louis Brennan, Esq., C.B., 1914.

The use of the gyroscope, as a means of enabling an unstable vehicle to remain upright when standing or running on a single rail, was patented by Mr. Brennan in 1903 and 1909. The model illustrates the arrangement of the gyroscopes and one method of automatic control, but the full sized car, built in 1909, has much more elaborate controlling mechanism.

There are two gyroscopes rotated, by electric motors, in opposite directions about horizontal axes situated normally athwart the car. These gyroscopes are mounted in frames which are geared together and are capable of turning about vertical pivots carried at the ends of a transverse frame which is itself mounted on an axis parallel with the length of the car. Two gyroscopes are necessary to enable the car to run in either direction on curves of any radius. When the car is standing upright with the gyroscopes running, a couple tending to overturn it causes the gyroscopes (which with their frames are called gyrostats) to turn or precess in opposite directions about their vertical axes, and in order to restore the car to its equilibrium position it is necessary to accelerate this precessional motion, which action brings into play a righting couple.

The outer end of each gyroscope spindle carries a roller driven by gearing at a reduced speed, while each gyrostat has an outwardly projecting arm along which slides a block provided with a downwardly projecting pin. On the body of the car are fixed horizontal surfaces, against which the spindle rollers can react by friction when pressed into rolling contact, so as to exert a force tending to accelerate the precession of the gyrostats, which force is substantially proportional to the reaction between the roller and the surface. On one side of the central position the downwardly projecting pins are guided, as regards radial motion, by cam-surfaces forming a circular groove, and on the other side of the central position the outer cam-surface is curved inwards so as to form a spiral guide, the depth of which is limited by a ledge. There is also another cam-surface on this side, forming a groove with the edge of the ledge and when the pin is in either groove the gyrostat roller can come into contact with its co-operating surface. The cam-surfaces are arranged so that the acceleration in one direction is caused by the spindle of one gyrostat, and that in the opposite direction is caused by the spindle of the other gyrostat. The two pivoted frames are connected

together by a helical spring attached to upright brackets, placed on the transverse axis but beyond the pivot centres, so that when the gyrostats precess, the spring tension also introduces an accelerating force which is sensibly proportional to the displacement.

The operation of the mechanism is as follows:—

On the application of a tilting couple to the vehicle, precession of the gyrostats takes place and is assisted by the spring and by one of the spindle rollers which comes into contact with its accelerating surface. During the righting motion the gyrostats move away from the central position and the projecting pin of the other gyrostat is lifted clear of its ledge and is moved inward by the spiral guide. When the equilibrium position has been passed, the action of the roller ceases and the pin of the other gyrostat is brought into contact with the ledge, so that the return motion of the gyrostats is at first retarded by the frictional contact. At a certain point in this movement the pin slips off the ledge into the groove, retardation ceases, and the roller on this side comes into play, so that accelerating force is again applied accompanied by the return of the gyrostats to their central position and of the vehicle towards its equilibrium position. Any slight deflection is now corrected by a repetition of this process, and the amplitude of the oscillations is quickly reduced to zero.

The car is mounted on four grooved wheels arranged as two bogies the frames of which have horizontal as well as vertical pivots. The driving motors are mounted over the outer wheels, with which they are connected by gearing, and the axles are connected by coupling rods. Current is supplied by accumulators carried in the car

Mr. Brennan's full-sized car is 40 ft. long, 10 ft. wide, weighs 22 tons and carries a load of from 10 to 15 tons. The gyroscopes are 42 in. diam., and each weighs 0·75 tons; they run in a vacuum at a speed of 3,000 revs. per min. The control is by compressed air and the current is supplied by two petrol electric generating sets. Inv. 1914—552.

951. Gyrostatic monorail car. Presented by Mons. P. Schilowsky, 1914.

This model shows a monorail car stabilised by a gyroscope which is controlled in the manner patented by M. Schilowsky in 1909. The arrangement of the gyroscope itself is, however, that patented by Mr. R. Scherl in 1908. A single gyroscope, with its axle vertical, is carried in a frame which is pivoted on the car about a horizontal transverse axis; this axis is placed below the centre of gravity of the gyroscope and frame, or gyrostat, so that the latter is unstably mounted on the car. It is claimed that this arrangement of gyroscope enables the car to travel round curves of ordinary radius without the use of a second gyroscope (*see* No. 950), that the gyroscope need only run at a moderate speed, and that it is more easily controlled.

When the gyroscope is spinning, the car will balance itself on the rail, and the application of a force tending to overturn it results in the gyrostat precessing about its horizontal axis. As soon as the gyrostat leaves the central position, its weight automatically accelerates the precession, brings into action a righting moment, and brings the car back to and beyond its original position. The gyrostat does not, therefore, precess in one direction, as a neutrally suspended one would do, but oscillates about its central position, causing the car to oscillate similarly but with a phase difference of 90 deg. If the gyrostat were left to itself these oscillations would increase in amplitude until the car fell over, and permanent stability can only be maintained by applying additional accelerating forces, by means of suitable mechanism, so as to damp out the oscillations and bring the gyrostat back to its central position when the car reaches its equilibrium position.

The precession of the gyrostat is controlled by a heavy pendulum mounted on the car so that it can swing in a traverse plane; this bears against a flexible cord fixed at one end and connected at the other end with the long arm of a horizontal lever which is pivoted on the pillar supporting

the gyrostat. The opposite and short arm of the lever has pivoted on it a vertical toothed quadrant normally held by a spring just out of contact with a pinion mounted on the top of the gyrostat and driven from its spindle at a reduced speed. The quadrant is held in the vertical position by a rod and springs, against the pressure of which it can move laterally. A similar mechanism on the opposite side of the car acts in conjunction with another pinion rotating in the opposite direction.

When the car is upright the pendulums hang vertically and the quadrants are clear of the pinions. When, however, the car leans to one side, the gyrostat precesses in the corresponding direction, and one pendulum bears against its cord and so raises its quadrant into engagement with the pinion. This imparts to the gyrostat an additional force tending to accelerate the precession, with the result that the car rights itself and moves slightly beyond its equilibrium position. The opposite pendulum then brings its quadrant into action and the oscillations of car and gyrostat are rapidly reduced to zero. If a load be placed on one side of the car, that side will rise until the centre of gravity is vertically over the rail, the gyrostat retaining its central position. Similarly on entering a curve, centrifugal force acting on the inner pendulum brings its quadrant into gear and causes the gyrostat to precess so that its reaction turns the car inwards to balance the centrifugal force. The quadrants can be adjusted in position or put out of action when necessary.

The car is mounted on a pair of two-wheeled bogies provided with vertical and horizontal freedom, and the wheels of one are driven by an electric motor; the gyroscope is also motor driven. It is intended that a train should be made up of ordinary cars and gyro-cars alternately, the connections being made with the special form of coupling shown on the model. Inv. 1914—185.

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952. Drawing of first tramcar used in America, 1832. (Scale 1 : 16.) Received 1913.

This represents the first horse car built for a street tramway; it was constructed by Mr. John Stephenson in 1831 for the New York and Haarlem street railway, which was opened in 1832. The car had a coach body with three compartments, and this was suspended by leather straps from a separate springless underframe carried on four wheels. The driver's seat was on the roof. The wheels were 3 ft. diam. and the wheel base was 5 ft.; the body was 14·3 ft. long and 5 ft. high. M.4074.

953. Models of tramcars. (Scale 1 : 24.) Presented by Z. Eastman, Esq., 1868.

The two models show a form of street tramcar introduced by Mr. Eastman in 1864. The tramway required consists of two shallow gutters in which the wheels run, thus resembling the early plateways and Train's tramway. The car wheels are without flanges, but have slightly rounded treads.

The axles are carried on central pins and races so that they can swivel, and the axles, whether two or three in number, are connected together by cross-bars or by segmental gear in such a way as to cause them to radiate horizontally when the horse pole is pulled sideways on passing a curve. M.1059.

954. Early electric tramcar truck. Presented by the South Staffordshire Tramway Co., 1912.

This is a four-wheeled tramcar truck built in 1892 by Mr. A. Dickinson for the South Staffordshire tramway; this was the second electric tramway

opened in this country with the overhead conductor system of current collection, and the first of the kind with British equipment. The line is of 3·5 ft. gauge and was originally worked by steam locomotives.

The truck has a frame composed of two pressed steel side-members, connected at the ends by angle-irons and at the centre by a transverse channel bar; this is carried on helical springs placed on the tops of the axle boxes, and the car body was mounted on eight springs placed on the top of the side frames.

The two motors, made by Messrs. Parker of Wolverhampton, are of the open type and have two-pole magnets, each pole being at the middle of a horizontal bar with a field coil on each side of it. The magnet bars are connected at the ends by yoke pieces having projecting pillars on both sides, to which are attached cast iron side frames in which the bearings for the armature shaft and running axles are formed. The inner ends of the motors are supported between helical springs resting on the central frame bar, and the armature shafts are connected with the axles by double helical steel gearing with a ratio of 4 : 1. The armatures have smooth cores and are drum wound; their undersides are partially protected by brass shields bolted to the lower poles. The brush holders are wooden levers pivoted at their lower ends on insulated studs, and having for brushes pieces of carbon 20 mm. diam. placed lengthwise along the commutator and held in brass V blocks bolted to the levers, the upper ends of which were drawn together by india-rubber bands. The four field coils of each motor are connected in parallel and in series with the armature; the controller was so arranged that either motor could be used separately or both in parallel, the necessary varying resistance being included in the circuit. The line pressure was 350 volts and the motors were rated at 15 h.p. each; the speed attained on trial was 36 miles an hour.

The truck has steel wheels 33 in. diam. and a wheel base of 6 ft.; brakes were fitted on both sides of the wheels. The car was constructed to carry 40 passengers, was 22 ft. long and 5·8 ft. wide; its weight unloaded was 6·65 tons. M.4036.

955. Model of maximum traction truck. (Scale 1 : 4.) Made by the J. G. Brill Co. Received 1911.

This represents an electric tramcar underframe mounted on a pair of the single motor trucks patented by Messrs. G. M. and J. A. Brill between 1893 and 1901. The so-called maximum traction truck was designed for use with large bogie cars, where only one motor is employed on each truck, and in order to utilise a large proportion of the adhesive weight of the car the load is concentrated almost directly over one of the axles, which is driven by the motor; the wheels on the other axle of the truck, owing to their wide swing, are made small enough to pass under a car body of normal height.

The truck has one-piece forged steel side frames which are securely braced together by two cross-bars. The frames rest on helical springs placed on the tops of the axle boxes, and the car body rests on side bearings only, which each consist of a head-piece mounted on two posts passing through a horizontal bracket projecting from the top of the driving axle-box guides, and also through the main frame; collars on these posts are supported on conical springs resting on the frame. The position of the bearings is such that 75 per cent. of the load is carried on the driving axle.

The bearing heads are loosely fitted for equalisation, and they have anti-friction plates on their upper surfaces and rollers at their outer sides which bear against the inner surfaces of the curved angle-plates attached to the side sills of the car. The tractive force is transmitted to the car frame by a vertical pin attached to a cross sill, and the lower end of this pin passes through a block that slides in a curved guide bolted to the truck; the guide has a radius struck from the virtual turning centre of the truck, which is at a point 6 in. from the driving axle on the inner side. In order to prevent derailment on curves, a spring pillar, mounted at the middle of the

truck cross-bar near the trailing axle, has its upper end bearing against a doubly inclined plate fixed to the car cross sill, so that the spring is compressed, and the load on the small wheels increased, when the truck swings round. A 25 h.p., single-geared, enclosed motor is carried between the axles, one end being mounted on the driving axle and the other bolted to a cross-bar supported by springs on the truck side frames. The wheels are of chilled cast iron 30 in. and 20 in. diam., and the axle boxes are self-oiling and dust-proof. The brake shoes embrace both tread and flange of the tires, and are hung by double links from brackets on the truck cross-bars; they are connected in pairs by cross beams and are applied to the tires by levers and rods. The blocks on the small wheels come into action first through the medium of springs, and the others when these springs are sufficiently compressed; other springs hold the brakes off. The brake levers at each side of the truck are coupled together by a curved bar upon which the brake rigging on the car acts through a rod ending in a roller fork; this allows the trucks to turn on curves without disturbing the brake adjustment.

The car underframe is a rectangular wooden framework strengthened by several cross sills, cross-braced at the centre, and provided with doors in the floor over the motors. The end platforms are supported by knees or cantilevers bolted to the main frame, and curved angle-iron buffer beams are fitted at the ends of these. Draw-bars are provided for use with trailer cars, and these bars can be housed under the platforms when not in use. Rail scrapers, which can be raised or lowered, are mounted below the platforms at each end.

The car is for the standard gauge of 4·7 ft., each truck has a wheel base of 4 ft., and the total wheel base is 12·5 ft. The small wheels of the trucks are placed towards the centre of the car. The length of the car body is 20 ft. and the overall length is 29·5 ft. Each truck with its motor weighs about 2 tons M.3912.

956. Model of high-speed truck. (Scale 1 : 4.) Made by the J. G. Brill Co. Received 1911.

This represents a type of railway truck or bogie patented by Messrs. G. M. and J. A. Brill in 1898 and 1899. It is much used in the United States for inter-urban electric services, where single cars are run at speeds as high as 60 miles an hour, but it is also considerably employed on ordinary steam railways. The features of the design are the method of equalising the load on the wheels through three sets of springs, and the cushioned side swing of the bolster which steadies the motion on curves and prevents derailment, especially where shallow wheel flanges are used.

The truck has two side frames, each formed as a single steel forging, and these are connected together by T bars at the ends and a pair of angle-iron transoms at the centre. The four axle-box horns on each frame are stayed by a continuous angle-iron bar. The load is carried on a wooden bolster with a centre pivot and side bearing plates, which is fitted between the transoms; the bolster is mounted on four elliptical springs, two at each end, which rest on a lower wooden beam enclosed by a pair of Z bars, that connect together two equalising bars suspended from the frames by spring links placed as near as possible to the axle boxes. On curves, the bolster and equalising bars move sideways, causing the links to swing on the frames and at the same time compressing their springs. Helical springs are placed between the frames and the tops of the axle boxes, so that the spring base is equal to the wheel base, and the application of the brakes does not result in excessive tipping of the truck. The brake blocks are suspended by double links from the end bars of the frame; they are connected by cross-bars, held off by springs, and applied to the wheels by levers mounted at the centre of the truck. Renewable shoes are attached to the brake blocks by wedges, and in order to preserve the adjustment on curves, the brake levers at each side are connected together through a pair of rods by a curved cross-bar to which the brake rigging of the car is attached. The whole arrangement leaves a clear space for the motors. The axle boxes are self-oiling and dust-proof.

The truck is driven by two single-geared motors placed between the axles and the bolster; one end of a motor is mounted directly on the axle and the other end is bolted to a cross-bar supported on springs on the transom. The motors on a truck of the size shown would be of 25–35 h.p each; it is suitable for loaded cars weighing up to 20 tons and can be run at speeds up to 50 miles an hour. The wheels are of chilled cast iron 33 in. diam., and the wheel base is 6 ft. M.3911.

957. Model of electric tramway truck. (Scale 1 : 4.) Made by the J. G. Brill Co. Received 1911.

This represents a type of equal-wheeled, centre pivot, bogie truck, patented by Messrs. G. M. and J. A. Brill in 1898 and 1900. It is largely used in America, and to some extent in this country, under long tramcars for city and suburban services where speeds up to 30 miles an hour are attained. The sharp curves on such lines necessitate a short wheel base, and this involves placing the motors beyond the axles, and supporting them on the ends of the truck. The features of the design are the method of equalising the load on the wheels through three sets of springs, and the cushioned side swing of the bolster which steadies the motion on curves and prevents derailment.

The truck has two side frames, each a single steel forging, and these are connected together by angle-bars at the ends, bent to give room for the motors, and a pair of angle-iron transoms at the centre. The axle-box horns are connected by a angle-iron bar at each side. The load is carried on a bolster composed of two steel plates, with wood between, and having a centre pivot and adjustable side bearings attached to it. The ends of the lower bolster plate are bolted to the centres of two semi-elliptical springs, the ends of which are hung from the side frames by spring links placed as near as possible to the axle boxes. The motion of the bolster on curves is cushioned by the springs of these links when they swing laterally. Compound helical springs are fitted between the frames and the tops of the axle boxes. The brake blocks are applied to the inner sides of the wheels, and are suspended by double links from the transoms; they are connected by cross-bars which are acted upon by central adjustable levers to apply the brakes, and by springs to release them. The renewable brake shoes are attached to the blocks by wedges, and they embrace both the treads and flanges of the tires so as to wear them equally.

The truck is driven by two single-geared motors of 25 h.p. each; one end of a motor is mounted directly on the axle, and the other end is bolted to a cross-bar supported on springs on the frame ends. The wheels are of chilled cast iron 33 in. diam., and the wheel base is 4 ft. The truck shown is suitable for a car weighing 17 tons, with equipment and passengers. M.3910.

958. Model of tramcar truck with radial axles. (Scale 1 : 6.) Lent by the Warner International and Overseas Engineering Co., Ltd., 1912.

This represents an electric tramcar truck fitted with the arrangement of non-parallel axles patented by Mr. J. S. Warner in 1905 and 1908. In this system all the axles of a vehicle are so mounted that while parallel to one another on a straight track they are free to set themselves radially to the track when rounding curves. This method of mounting allows the vehicle to pass smoothly round curves; shocks and oscillations are reduced, thus minimising the wear of rails and tires, giving the vehicle a much steadier motion and requiring less tractive effort.

The truck is built up of steel channel bars, cross-braced at the ends and at the centre, where there are fitted two vertical pins. Each axle is mounted in bearings in a separate open frame, the latter being pivoted to the main frame by one of the pins. Opposite each axle end two brackets project downward

from the main frame and are connected at the bottom by a cross-bar. This cross-bar is suspended from the axle frame by two links, one on each side of the axle box, the link pins being set radial to the pivot pins. The upper parts of the links are surrounded by the helical bearing springs, which are supported by lugs on the axle boxes. The effect of this suspension is that on a curve the axles are set radially by the action of the rails on the wheel flanges and the links in swinging raise the vehicle slightly, giving a gravitational control which restores the axle to its normal position on leaving the curve. No bearing pressure comes on the centre pivots.

The brake gear is mounted on the axle frames and has brake blocks on the inner sides of the wheels only; the connections with the main frame are made by pin joints directly under the turning pivots, so that the gear is not affected when the frames turn. The car body is carried on eight helical springs suspended below the main frame slide sills. The truck is fitted with a safety guard under each platform. This consists of a flat-hinged guard normally held horizontally, but so connected with a hanging flap at the end of the platform that it is lowered on to the rails when the flap is pushed backward by an obstacle. The guard is restored by a pedal on the platform.

The model shown represents a four-wheeled tramcar truck for the standard gauge, with wheels 30 in. diam. and a wheel base of 9 ft. The system is applicable to all kinds of railway or tramway rolling-stock and especially to large bogie vehicles. M.4044.

959. Early cast iron wagon wheel. Presented by H.G. the Duke of Rutland, K.G., 1904.

The wheels of the wagons used on the early wooden railways were described in 1676 as "rowlets fitting the rails," and were probably double-flanged wooden wheels, but in 1734 wide single flanged cast-iron wheels were in use on a wooden railway near Bath. The example shown, however, is a narrow single-flanged cast iron wheel for running on metal rails, and is from the cast iron edge-rail line connecting Belvoir Castle with the Grantham Canal (*see* No. 811), where it was in use from 1793 to 1903.

The wheel is now 22·75 in. diam. and 3·5 in. wide on the tread, into which, however, a deep groove has been worn, partly owing to the very narrow face of the rails. It ran loose on the conical end of a fixed axle and was secured by a washer and split pin; the arms are curved so as to prevent fracture by cooling stresses after casting. M.3312.

960. Mansell's railway wheel. Contributed by the Commissioners of the Great Exhibition of 1851.

This construction of railway wheel, introduced in 1848 by Mr. R. C. Mansell, is now almost universally used for passenger carriages. The wheel consists of a rolled tire and a metal boss, but instead of spokes the wheel is made up of solid sections of hard wood with the grain arranged radially. At the centre the wood is held between flanges, and at the rim between two rings bolted together by through bolts. The tires are rolled with a groove on each side, and the rings have corresponding ridges formed on them, and in this way the tire is secured to the rest of the wheel. The great advantage of this method of attachment, which is also used for wheels with iron spokes, is that should the tire break, even in several places, the segments will still remain on the wheel, and thus the probability of derailment through a fractured tire is reduced. The wooden portion of the wheel has an important action in reducing the noise and jolting of the wheel, as it gives a certain amount of elasticity, and even where iron arms are used a wooden packing near the tire is sometimes introduced. The wooden sections are here shown dowelled together with metal plates, but the latter are now generally dispensed with. M.140.

961. Railway wheel with broken tire. Presented by R. Brotherhood, Esq., 1861.

This wheel, made by Mr. Brotherhood, has a wrought iron boss, arms, and rim, with the usual flanged tire held continuously by securing rings as in No. 960. This tire has broken, but the tire fastening has retained it in place although the wheel ran 115,000 miles after it had been fractured. M.982.

962. Oil axle-box. Contributed by D. Dietz, Esq., 1862.

This is a sectional example of an axle-box for railway carriages, patented by Mr. Dietz in 1860. The lower front portion of the box forms an oil reservoir, which is closed at the back by a partition and a half-collar which is forced upward against the journal by a spring. Any oil leaking past this partition collects on a saucer-shaped disc secured to the axle, and the edge of this disc is continuously wiped by a hinged finger which returns the oil on to the top of the bearing. The inner end of the box is closed by a millboard disc to exclude dust. M.767.

963. Buffer for rolling-stock. Contributed by Messrs. John Spencer & Sons, 1860.

This is a sectional example of a construction of spring buffer introduced by Messrs. Spencer and Mr. H. L. Corlett in 1854. The plunger is provided with a projecting collar at the back, which, by coming into contact with an internal projecting collar at the neck of the fixed casing, limits the forward travel. After the plunger has been placed in position the head is riveted to it; a volute spring is then inserted behind them in the casing and, while under compression, is fixed in position by a back cover secured by four interlocking lugs forming bayonet joints. M.394.

964. Railway buffer and drawing. Lent by Messrs. Ibbotson Bros. & Co., 1891.

These show in section a modern buffer for absorbing the concussions of rolling-stock. It consists of a solid steel head and plunger with a reduced tail, on which a flanged collar with an elliptical exterior can, by means of the special wrench shown, be screwed up solidly against the shoulder on the plunger. The plunger is carried in a casing bolted to the buffer beam, and encloses a volute spring under considerable compression. The base of the casing is formed by an iron plate with a central hole, through which the tail of the plunger passes, and is so kept in line. Messrs. Ibbotson's locking nuts are employed on all the bolts shown. M.2366.

965. Model of link and pin coupling. (Scale 1 : 8.) Lent by A. H. Higgins, Esq., 1900.

This form of coupler was, until 1880, almost universally used for goods wagons in America, where central buffers are generally employed. Each buffer has a horizontal slot in its face, through which a long link is inserted and there secured by a vertical pin dropped in at the back of the buffer; the other end of this link is similarly secured by a pin behind the corresponding buffer. In coupling, the shunter had to remove the pin by hand and replace it after the link had been inserted, the whole operation being both difficult and dangerous. M.3105.

966. Model of automatic coupling. (Scale 1 : 4.) Presented by Louis Sterne, Esq., 1895.

The model shows a pair of buffers fitted with a form of coupling introduced by Mr. Sterne about 1874. It is intended for vehicles with a single

central buffer, and is so constructed that the contact of the buffer secures the coupling together of the two trucks without other assistance.

The buffers are formed with a central cavity in which loosely fits a long link. At the back is a vertical pin which, when dropped as low as it will go, is passing through the long link, so closing the coupling. Before coupling together, the link is pinned into one of the buffers, while the other buffer has its pin supported by a horizontal roller so arranged that the link, when entering, pushes the roller away and is itself secured by the falling pin. When the pin is lifted for uncoupling, the roller by gravity returns to its supporting position. M.2736.

967. Models of "Janney" couplings. (Scales 1 : 4 and 1 : 8.) Lent by the Rt. Hon. Sir F. J. S. Hopwood, K.C.B., G.C.M.G., 1900.

In 1879 Mr. Eli Janney, of Pittsburg, U.S.A., patented a vertical plane car-coupler having a lateral moving knuckle; in 1887 the arrangement was accepted by the Master Car Builders' Association of America, with the result that the various modifications of the arrangement in use are classed as M.C.B. couplers. It was then adopted as the American standard goods coupling, and its use has since been greatly extended to rolling-stock of all kinds.

The Janney coupling consists of a steel jaw fitted on one side with a knuckle or L-shaped lever turning on a vertical pin; this knuckle when being swung inward lifts a locking pin which subsequently drops and so prevents the return of the knuckle. An identical coupler is fitted to the end of the adjacent vehicle, and, so long as both or either of the knuckles are open when the vehicles come into contact, coupling will be effected; to uncouple, it is only necessary to raise either of the locking pins, by means of a chain or lever at the side of the vehicle. The knuckles have each a hole in them to permit of the use of the old link and pin coupler, when such a fitting is met with. At first this coupling gave some trouble through the locking pins occasionally creeping upward, but in the larger model, which represents the later form, there is an automatic locking pawl that prevents this motion; owing, however, to the pawl being attached to the lifting shackle, it in no way interferes with the pin being raised when disconnecting. M.3104.

968. Combination automatic coupling. (Scale 1 : 4.) Presented by T. Wharton Ford, Esq., 1911.

This represents the coupling arrangement patented by Mr. W. S. Laycock in 1899; it is intended for use during the transition stage, when automatic couplers are being introduced, and during which it is necessary that vehicles so fitted should couple up with others fitted with ordinary screw or chain couplings.

The automatic coupler is of the M.C.B. type, but, instead of being made in one with the drawbar, it is made separate, and is pinned to the hooked end of the drawbar so that it can swing downwards when not required, leaving the hook free for use with the ordinary couplings. When in use the coupler is held up by a pin passing through it and resting in the opening of the hook.

In the coupler shown the knuckle is locked by a vertically moving pin held down by a spring; it is unlocked from the side of the vehicle by a pull on a chain attached to a bellcrank lever that pushes up the pin from below, the knuckle being forced open by the same spring, so that it is always ready for recoupling without having to be opened by hand. M.3833.

Railway Brakes.

969. Model of a continuous brake. (Scales 1 : 4 and 1 : 8.) Presented by James Newall, Esq., 1862.

This is an early form of continuous brake, patented by Mr. Newall in 1852 and 1857. Each vehicle of the train is provided with a brake gear, and also with a powerful helical steel spring by which the brake is applied. Running

through the length of the train is a shaft connected between the carriages by universal joints, and this shaft can be rotated by a hand wheel fixed in the guard's van, and which, by gearing, winds off the brakes, and compresses the helical springs throughout the train. The brake is held off by a ratchet in the guard's van, where also is a clutch by which the gearing can be released and so the springs be allowed to act. A flexible cord runs the length of the train so that the brake can also be at once applied by the engine driver. While this brake embodies some features of modern appliances, it could never have been sufficiently powerful for the requirements of the present day.

Inv. 1862–108.

970. Model of the Westinghouse brake. (Scale 1 : 4.) Made by the Westinghouse Brake Co., 1886.

The Westinghouse continuous automatic pressure brake is, as its name implies, a brake that is applied to all the wheels throughout the train, and which, when through any accident the train is broken or the apparatus deranged, is automatically applied. The power by which this is effected is fluid pressure, the medium being compressed air stored at a pressure of 75 lb. per sq. in. above that of the atmosphere.

The Westinghouse is the form of continuous brake most extensively adopted, although many other modifications have been introduced and are largely used. In a train so fitted the engine is provided with a vertical direct-acting air-pump driven by steam from the engine boiler. The air so compressed, after passing through a regulator valve under the control of the driver, enters a pipe which is continuous throughout the train, the connection between the carriages being made by flexible hose, with an interchangeable and readily made union. To the engine and beneath each carriage an air reservoir is fitted, and also a cylinder containing a single-acting piston, the piston rod of which is connected with the brake levers of each vehicle. The return stroke of this piston is caused by the action of a helical spring, which thus pulls the brakes off. Each air reservoir is fitted with a box containing a triple valve, which, when the pressure in the train pipe is reduced, opens a connection between the air reservoir and the brake cylinder, so that the compressed air can force out the pistons and so apply the brakes. If, therefore, a train should be divided through the failure of a drawbar or like accident, the air in the train pipe escapes, and the resulting fall in pressure at once applies the brakes throughout both portions of the train. On the engine and also on each guard's van is fitted a valve by which the air pressure in the train pipe may be lowered and so the brake be applied as required. These valves are so constructed that the application of the brakes may be rapid and powerful or only moderate, as the circumstances may demand. Gauges are fitted both on the engine and in the guards' vans by which the pressure of air in the apparatus may be observed. After a stop has been made the brakes remain on until the engine-driver, by his large store of compressed air, restores the train pipe at once to full pressure.

The model shows a four-wheeled carriage frame fitted with the Westinghouse brake. The arrangement of brake levers is such that the four brake blocks to each pair of wheels are simultaneously applied, and with equal pressure, by the outward movement of the brake pistons. The brake reservoir and its triple valve are arranged near the side of the framing, and the engine reservoir with a hand air-pump are attached to the table on which the model is carried, and the driver's regulating valve on the right-hand side. By the length of flexible tubing introduced, the model can run on the metals, and the brake be worked experimentally.

The large adjacent wall diagram shows the arrangement of the air pump, the driver's and the triple valve, together with the general arrangement of the brake cylinders and reservoirs. M.1637.

971. Westinghouse brake gear in section. Made by the Westinghouse Brake Co., 1888.

This is a full-size example of the improved Westinghouse brake cylinder and reservoir, with the mechanism shown in section. It differs from the earlier

pattern in that the reservoir is combined with the cylinder, so forming a more compact arrangement. The cylinder is at one end of the reservoir and the triple valve at the other. The air passed from the reservoir by the triple valve to the brake cylinder is conveyed by steel tubing running the length of the reservoir. M.2255.

972. Model of automatic vacuum brake. (Scale 1 : 4.) Lent by the Midland Railway Co., 1897.

This shows a carriage underframe, with wheels, axle-boxes, etc., complete, fitted with the automatic vacuum continuous brake, in which there is a train pipe, with flexible connections and simple couplings, which communicates with the brake cylinder of each coach and is exhausted by a steam-jet apparatus on the engine. So long as the pressure in the pipes is below that of the atmosphere, the brake blocks remain off; but if, through the breakage of a pipe or the opening of a valve by a guard or driver, atmospheric air is allowed to enter, the whole of the brakes are applied with an effective pressure of about 12 lb. per sq. in.

The brake cylinder, shown in section, is arranged vertically, and to save the height occupied by a connecting rod is carried in trunnions as an oscillating cylinder; the piston is packed by a rolling ring of india-rubber. The upper face of the piston is open to the vacuum reservoir, while both faces are, by a valve box, placed in communication with the train pipe. The valve box, however, contains a small ball valve which, on a sudden inrush of air, closes the entrance to the vacuum chamber, but permits the air to enter the space beneath the piston and so apply the brake. For shunting purposes a light wire is fitted by which the brake can be released from either side of the carriage. M.2984.

973. Combination ejector. Lent by the Vacuum Brake Co., Ltd., 1908.

This is a sectioned specimen of the standard type of combination ejector for the automatic vacuum brake, patented by Mr. J. Gresham in 1878–81.

A single fitting combines within it two ejectors, with their valves, and the air valve for applying the brakes. There is a large ejector for rapidly exhausting the air from the train pipe when removing the brakes, and a small one, placed on its axis and at the rear part of it, for maintaining the vacuum against leakage when running; these communicate with the train pipe and are fitted with non-return valves. Steam enters through a pipe at the top of the casing and the train pipe is attached to a flange below. The small ejector is continually supplied with steam through a screw-adjusted valve, but its air supply is cut off when the brakes are applied. The large ejector has its steam supply controlled by a disc valve, working on a horizontal axis, to the end of which is attached a handle, the enlarged boss of which serves as a disc valve which admits air to the train pipe when the brakes are to be applied; this valve is hollow and works against a flat face on the casing, while the air is admitted through perforations in its back. There are three positions for the handle; first, the mid or "running position," when the steam to the large ejector is cut off, the air valve is closed and the small ejector is working to maintain the vacuum; second, the rear or "brake on" position, when both ejectors are cut off and the air valve destroys the vacuum in the train pipe, thus applying the brakes; and third, the forward or "brake off" position, when the air valve is closed and both ejectors are in action for rapidly removing the brakes. The brake power may be varied by placing the air valve handle in intermediate positions. The fitting is bolted by a flange to the back plate of the locomotive fire box and an internal pipe conveys the exhaust steam and air to the smoke box where it acts as a blower. Drain pipes are fitted to carry off any water which may collect in the apparatus. M.3530.

LIFTING MACHINERY.

Jacks, Winches, and Cranes.—For lifting heavy masses the two most elementary machines are the crowbar and the windlass. The former, requiring no overhead structure, represents the appliance most used for temporary or emergency work. The screw jack (*see* No. 974) and the still more powerful hydraulic jack (*see* No. 977) are most useful and convenient substitutes, and the greatest lifts yet performed have been made by large hydraulic rams.

The windlass, as represented by the cottage well-head gear, has developed into the more powerful winch, which, when provided with a head gear of its own, capable of swivelling, formed a crane which again became a derrick when fitted with an arrangement for varying the radial distance of the load. The travelling crane is simply a winch carried on overhead rails upon which it can move and so convey its load, when raised, to any position within the enclosed area. The work entailed in lifting a load being so great, the time lost in doing the work by hand is serious, so that for most purposes power is employed. This is generally in the form of a simple high-pressure reversing steam engine, but frequently the power of engines employed for other work is conveyed to the winch either by shafting, or by a fly-rope (*see* No. 997), or now, very generally, by a cable delivering its current to an electric motor (*see* No. 998). In most lifting machines using chains or ropes some form of pulley-block is introduced to obtain a portion of the requisite mechanical advantage, and during recent years the improvements in the construction of flexible wire ropes have led to their extensive employment in this way in place of the more cumbersome and noisy chains so long in use.

For many lifting machines the hydraulic system is adopted, the ram sometimes acts directly, but usually its stroke is multiplied by the reversed pulley-block arrangement introduced by Lord Armstrong. The losses through friction in this machine increase with the extent to which the stroke is multiplied, hence the tendency in the construction of the more recent machines is to diminish this loss by adopting long-stroke cylinders.

Lifts and Elevators.—The great height of buildings, and the waste of power in raising the weight of the whole body when only a light weight is required to be conveyed to a higher story, have led to the extensive use of passenger lifts, and of smaller ones for domestic use to be worked by hand. The passenger lift consists of a cage or small room controlled by vertical guides, and capable of being lifted or lowered in a shaft or well-hole that passes up through the building. The power used is frequently that of a steam or gas engine, but, where obtainable, hydraulic power or electricity is more convenient. The weight of the empty cage is nearly counterbalanced by a weight so that the useful load alone is that upon which the work is done. For safety some form of clutch gear is always fitted, which, should the

lifting ropes fail, will at once seize the guides and retain the cage. A long, direct-acting hydraulic ram, acting on the floor of the cage, is also frequently used instead of an overhead lifting rope, and, with a hydraulic balance, forms an efficient and economical arrangement. Domestic lifts are usually small open-fronted boxes steadied by suitable wooden guides secured in the well-hole. A rope passes from the top of the cage up to an overhead V-grooved pulley and then down to a counterbalance weight sliding between the guides. Manual power is transmitted to the overhead pulley by an endless rope hanging from a large pulley on the main axle, but where the loads to be lifted are considerable, spur gearing is generally introduced to increase the mechanical advantage obtainable by the pulleys. A simple friction brake is usually added, and in some cases the brake is applied automatically when the hand rope is left free. Water power and electricity from the public supply companies are also extensively used for working these small lifts.

A form of lifting appliance of very great capacity is represented by the ladder dredger (*see* Marine Engineering Section) in which a closed chain fitted with buckets travel continuously; the full ones being on one side and the returning empty ones on the other. For grain and similar materials such elevators (*see* No. 1007) are very convenient, and for lifts this device is also employed, but, owing to the continuous motion, the speed must be slow to permit of the load being placed on the platform or hooks.

Jacks, Winches and Cranes.

974. Screw-jack. Received 1883.

This is an ordinary "bottle" jack for lifting a load of 2 tons. It has a square-threaded screw, 1·5 in. diam. and 0·5 pitch, which can be turned by an iron lever inserted into either of the two transverse holes through it. The top of the screw is provided with a loose swivelling cap. M.1675.

975. Traversing screw-jacks. Contributed by G. England, Esq., 1869.

These are respectively the original and a later form of the traversing screw-jack patented by Mr. England in 1839. The essential feature of the invention is the addition of a slide and a horizontal screw beneath an ordinary jack, by means of which the load, when raised, may be moved laterally.

In the earlier form the vertical screw is turned by a bar and the horizontal one by a ratchet lever; the screws have ordinary V threads, though in the specification both screws are represented with square threads. In the later form (1869) the screws are square threaded, and both are provided with ratchet braces.

Traversing jacks have since been very extensively used, *e.g.*, nearly all locomotives carry them for use in replacing the engine should it become derailed. M.1176–7.

976. Haley's screw-jack. Received 1883.

This construction of jack was patented by Joseph Haley in 1840, and has been extensively used. The body is of timber plated with iron, and has a slot

in it which serves as a guide to a vertical square-threaded screw, whose lower end is provided with a lifting claw, while the top has a swivel cap. The nut of the screw is formed into a worm wheel which engages a horizontal worm rotated by a double-ended winch handle. In the example shown, which is intended for a load of 2 tons, the handle moves through 805 times the distance travelled by the screw. M.1677.

977. Hydraulic jack. Made by Messrs. Tangyes, Limited, 1888.

This is an improved form of the lifting jack patented by Messrs. James and Joseph Tangye in 1857, in which, by the combination of a small force pump and a hydraulic cylinder, great lifting power is obtained in a portable machine of considerable range.

The jack consists essentially of two steel castings, the upper one forming the hydraulic cylinder and containing also the force pump, while the lower one is the ram or plunger which terminates in a flat foot. The top of the cylinder casting forms the lifting head and also forms a reservoir or tank, while at the bottom is a projecting lip for use when the head-room is insufficient for the insertion of the whole jack. The force pump is worked by a hand lever, and pumps water or some non-congealing fluid mixture from the reservoir into the hydraulic cylinder, thus lifting it; when lowering is to be performed, a small by-pass valve projecting from the side of the cylinder is slightly opened, and this allows the fluid to pass back again into the reservoir.

The jack shown lifts 3 tons; it has a cylinder of 1·75 in. bore, while the ram of the small force pump is 0·875 in. diam. M.1676.

978. Hand winch (working). Presented by the Harrison Manufacturing Co., 1890.

In this winch, which was patented by Mr. J. Harrison in 1889, the mechanical advantage is obtained by the use of epicyclic gearing. The shaft to which the winding drum is secured extends right through, and has a pinion of 12 teeth keyed to it. Loose on this shaft are a pinion of 11 teeth, which by a clutch is held stationary, and the winch handle, the lever of which extends backward and carries a stud on which are two pinions cast together and free to turn, but having 11 and 12 teeth respectively; the one with 12 teeth gears with the dead wheel and that with 11 teeth gears with the wheel on the drum shaft, the result being that 6·2 turns of the handle are necessary to cause one revolution of the drum. The load will not run down when the handle is released, so that the winch is self-sustaining, but by lifting the catch which retains the dead wheel the drum is released. The example shown is for lifting a load of 3 cwt. directly from the barrel. M.2350.

979. Model of a steam winch. (Scale 1 : 8.) Lent by W. Smith, Esq., 1862.

This compact arrangement of the directly-driven steam winding engine now so extensively used on shipboard, etc., was patented and introduced in 1853 by Mr. J. Taylor of Birkenhead.

Two inclined cylinders, at the ends of the framing, work upward upon disc cranks set at right angles on a shaft having a pinion on it which gears directly with the spur wheel on the barrel or winding shaft; a slower speed and greater purchase are also obtainable by bringing into gear a second shaft which is, moreover, fitted with winch handles for use when steam is not available. The cylinders are fitted with link motions, simultaneously reversed by a single lever, and the drum is provided with a large band brake applied by a foot lever, by which the lowering of a heavy load may be controlled.

At each end of the drum shaft are overhanging warping drums, round which it is usual to take one or two turns of a hauling rope, so as to be able to control the lifting or lowering by varying the tension on the slack end. By making these drums conoidal the rope continuously slips axially while being wound in, and thus avoids riding upon itself. M.331.

980. Model of a horizontal winding engine (working). (Scale 1 : 16.) Made about 1870.

This represents a colliery winding engine. It has a pair of double-acting horizontal steam cylinders acting on a common crankshaft, with overhanging cranks set at 90 deg. The winding drum is arranged for two ropes, one being let out as the other is drawn in, so that the weight of the cages is neutralised as well as that of a portion of the rope. To counterbalance the weight of the rope completely, however, a form of fusee is adopted—a spiral groove being cut on the conical faces of the winding drum, whereby the mechanical advantage of the machine increases when a great length of rope is down the mine, as then the radius of the drum is considerably reduced. After the spiral groove is filled the rope is wound on the parallel portion of the drum, but by suitably proportioning the spiral ends the correction obtained can be made as regular as would be the case with a spiral drum throughout. The spirals shown, however, give a much greater difference between the extreme diameters of the rope path than is usually required. In the middle of the drum is a brake strap connected with a lever which is actuated by a vertical steam cylinder of the trunk construction. Steam is supplied to this cylinder through a small slide valve under the immediate control of the engine-driver. The supply of steam to the engines is regulated by a disc throttle valve, and reversing is performed by the shifting link motion. The three controlling handles are brought near together, so that the whole machine is perfectly under the control of one man. In these cylinders the piston rods are continued as tail rods through the back covers, the chief object of which arrangement is to remove the weight of the piston from the lower side of the cylinder, which otherwise would wear oval. M.2558.

981. Model of winding engine (working) and semi-portable boiler. (Scale 1 : 8.) Received 1899. Plate XII., No. 1.

This mining engine consists of a pair of horizontal cylinders arranged on a wrought iron girder frame, which also supports the multitubular boiler; one end of the frame forms a closed ash pit, while the other supports the two steam cylinders, above which is a cradle carrying the smoke box end of the boiler. The engine has link-motion reversing gear, a plunger feed-pump, and a strap-brake on the flywheel.

One end of the crankshaft carries a pinion gearing into a large spur wheel on an outside drum shaft, which is frequently fitted, as shown, with an overhanging crank for driving mine pumps when required. Running loose on this shaft are two winding drums, and between them is a pair of claw clutches, by which each can be thrown into or out of gear; each drum is fitted with a strap-brake, so that either can lower its load by its brake, even while the other is winding. M.3073.

982. Friction-driven hoist. Lent by Dr. H. S. Hele-Shaw, F.R.S., 1885.

This is an application, by Mr. Edward Shaw, of Dr. Hele-Shaw's sphere and roller mechanism. When first introduced in 1884 this device was used on a calculating machine, but in the present example the variable velocity ratio is employed to control the motion of a friction-driven hoist.

The driving belt imparts motion to the pulleys, of which one is fast and the other loose. A disc with conical rim, acting as a friction-wheel, presses against and turns the sphere. Another disc, with rim similar to the first,

is attached to the short drum, round which the lifting rope is coiled. The relative velocity and direction of the motion of the drum depend upon the position of the axis of rotation of the sphere. This axis may be changed instantaneously, and the direction of motion reversed, or the speed altered, by means of the handle which moves the pivoted frame above the sphere. M.1631.

983. Model of hydraulic capstan. (Scale 1 : 4.) Lent by Messrs. Sir W. G. Armstrong, Whitworth & Co., 1899.

This form of water-pressure engine or hydraulic motor, for driving a capstan, was introduced in 1851 by Lord Armstrong; he had in 1848 patented a water motor with two diagonal cylinders acting on a single crank, and still earlier had constructed and tried with satisfactory results a rotary motor resembling the engine described in No. 136, but the three-cylinder engine shown is that which has been most extensively adopted.

The cylinders are single-acting and of the oscillating type, placed side by side, and working on a three-throw crankshaft, which is connected with the capstan by spur and bevel gearing, having a ratio of 3 : 1, so arranged as to increase the hauling effort of the capstan. The cylinder trunnions are hollow and are provided with ports, so that by their oscillation they act as valves in admitting and discharging the driving fluid through corresponding ports formed in a hard metal ring in the bearings. This hydraulic engine is generally arranged below the ground level, so as to be out of the way of those working the capstan; in many installations the engine bed is provided with trunnions, so that the whole arrangement can be turned over, to facilitate inspection or repair of the working cylinders. M.3084.

984. Model of Perronet's jib crane. (Scale 1:24.) Made in the Museum, 1914.

This crane was designed by the French engineer Jean Rudolphe Perronet for the work of setting the voussoirs of the bridge built by him in 1751–9 over the river Loire at Orleans.

In the Dutch or walking crane, dating prior to the 15th century, the load was lifted by animals working a horizontal or vertical treadmill incorporated with a jib or else close to one. In both cases the machine formed part of a permanent structure. Perronet's crane was self-contained, so that it could be moved from place to place. The power to wind the rope on the axle was applied at the circumference of a drum. Although neither in this nor in the older crane was there a pawl or brake to control the load, yet there was less danger to limb with Perronet's than with the older crane.

The crane post was stepped in cross-timbers and strutted; at the top there was a socket on which the jib with its framing could turn through a complete circle. Bearings in the framing accommodated the axle on which was a drum turned by one or two men by hand pins, the whole being in balance. The loads to be lifted were small, so there was no gearing.

The radius of the jib was 22 ft.; the drum, 10·5 ft. effective diam. and the axle 11 in. diam. The load was 380 lb. and the rope 6·5 in. circumference.

(*See* Perronet—"Description . . . de la construction des Ponts de Neuilly . . . ," 1783.) Inv. 1914–572.

985. Model of jib crane. (Scale 1 : 12.) Presented by Messrs. Bullivant & Co., 1902.

This represents an early form of warehouse post crane, to be worked by manual power. It is constructed wholly of iron, and the post, jib and back stays are all forgings, held together by bolts. The post is capable of rotation on a footstep bearing in the basement, or on a lower floor, and a collar bearing at the working level, but no mechanism is provided for slewing, as this motion can be performed directly. The lifting gear is attached to the post

and can be made single or double purchase at will, by sliding the pinion shaft; the total ratio of the spur gear is 1 : 23. The second motion shaft is provided with an iron band brake for use in sustaining or lowering a load.

M.3218.

986. Model of hydraulic crane. (Scale 1 : 12.) Lent by Messrs. Sir W. G. Armstrong, Whitworth & Co., 1899. Plate XII., No. 2.

This closely resembles the crane erected at Newcastle quay in 1846 by Lord Armstrong, when he patented and first introduced his system of hydraulic machinery; its success was such that complete installations of hydraulic lifting appliances were soon erected by him at Grimsby, Liverpool, and elsewhere. The leading feature of the crane is that the comparatively short stroke of a hydraulic cylinder is multiplied, by causing it to move the block of a pulley tackle, so that an ample range of lift together with high lifting speed are secured.

The early crane represented has a hydraulic cylinder fitted with a pulling piston, the rod of which carries a sheave and also the end of the lifting chain, by which arrangement, together with an external fixed pulley, the lift of the crane is made equal to three times the travel of the piston. The cylinder is arranged underground at a slope of 1 in 27, so that gravity assists in running out the chain; friction is reduced also by roller guides supporting the crosshead. For use in slewing, the crane is provided at the base of the post with a spur wheel, into which gears a rack attached to the piston of a small horizontal double-acting hydraulic cylinder. The lifting and slewing are controlled by slide valves worked by hand-levers, and the crane hook is provided with a weight sufficient to keep the chain tight during the return stroke of the lifting piston.

M.3082.

987. Model of a weighing crane. (Scale 1 : 8.) Contributed by the Kirkstall Forge Co., 1860.

The adaptation of a crane to the further purpose of weighing the load lifted has been accomplished, either by measuring the pull on the chain, usually by some form of suspended weighing machine, or else, as in this example, by directly measuring the increase in weight of the whole crane due to the load lifted. This latter method was patented as early as 1837 by Messrs. Hitchin and Oram, but the construction here shown was extensively introduced in France by M. M. George about 1844, and in England by Mr. J. O. Butler in 1858.

The crane is of the jib type, worked by hand power, and has single and double purchase gear, convertible by sliding the winch handle shaft; there is a band brake on the second motion shaft, and a ratchet wheel for a retaining pawl on the chain drum, the surface of which has a helical groove to ensure smooth winding on of the chain. The crane is carried on a circular table, which has projecting from its lower surface a crane post resting in a footstep at the bottom of the foundation and supported by a socket in the upper foundation plate. This plate is formed with an internal spur ring with which engages a pinion carried on a vertical shaft by which the crane is slewed.

The modification in the crane, by which the weighing is performed, consists in connecting the jib, the gearing and its brackets into one rigid frame, which is attached to the remainder of the structure by links and knife edges. Outside the gear framing are two standards secured to the revolving platform, and to these the framing is tied on each side by an upper and lower horizontal link connecting knife edges; in this way the overturning moment of the crane is neutralised by a pair of horizontal forces, or a "couple," while the downward force, representing the weight of this portion of the crane together with its load, is unaffected. This downward force, which resembles the shearing force in a girder, is resisted by a lever turning

on a fulcrum attached to the platform and pressing on a knife edge under the jib frame, while the other extremity is provided with a heavy scale-pan and movable weight; the pan balances the weight of the crane, so that proportionate weights placed in the pan will give the weight of the load.

Except when weighing has to be done, the crane brackets are lowered on to the main platform and the knife edges thrown out of action by a cam, which lifts the scale beam and locks it. M. 333.

988. Model of crane with automatic balance. (Scale 1 : 16.) Lent by Robert Pirie, Esq., 1896.

This construction of automatic balanced crane was patented by Mr. Pirie in 1885.

It is of the jib type, but has a projecting bracket behind that forms a pair of curved rails, on which run flanged wheels connected with a counterbalance weight. The crane hook terminates in a sheave round which passes a lifting rope; one end of this rope is attached to the winding drum of an ordinary hand gear, while the other end goes round the sheaves of a hydraulic ram and cylinder, and is then made fast to the framing. From the lifting rope also extend two light ropes which, after passing over the sheaves on the tail bracket, are attached to the balance-weight. The hydraulic cylinder has a by-pass, and when a load is to be lifted the increasing tension on the lifting rope slowly passes the water from the cylinder, thus allowing the balance-weight to be pulled up the inclined guides. The framing is carried on a central post, on which, at the base, the frame can slightly rock; when the balance-weight has moved out far enough, the slight rock backward moves a wedge that closes the by-pass valve of the hydraulic cylinder, and so prevents further movement of the counterbalance.

The crane, being always completely in balance, requires no holding down, and in the model is shown carried on four columns with rails running between. M.2958.

989. Model of traversing sheer legs. (Scale 1 : 24.) Presented by Messrs. Day and Summers, 1868.

Sheer legs consist of two nearly vertical masts lashed together at the top, and there supporting a pulley tackle. This arrangement is free to swing to and fro, but its motion is restricted by guy ropes, so that by manipulating these ropes a load, while lifted by the legs, can be traversed horizontally. For erecting masts in a ship the sheer legs used are generally built on a dismantled hull known as a sheer-hulk. When a third leg is added, the arrangement becomes a tripod, which is much more secure, but less convenient, as it is almost useless for traversing a load.

In 1862, however, Messrs. C. A. Day and T. Summers patented a tripod in which the back leg was capable of being traversed in a guide by mechanical means, and the model generally represents the first traversing sheer legs constructed, which was erected by them at Southampton in 1863.

The legs are built of 0·5 in. plate with double-riveted butt joints circumferentially and single-riveted joints longitudinally. The front legs are of 110 ft. effective length, 20 in. diam. at the ends and 40 in. diam. at the middle, and the back leg is 138·5 ft. long. The latter has its lower end secured to a nut, travelling in horizontal guides and moved by a screw, 8·5 in. diam. and 48·25 ft. long, which is rotated through gearing by a pair of high-pressure steam cylinders, 12 in. diam. by 15 in. stroke. The total traverse for a load is 47 ft., of which 32 ft. are beyond the quay wall. The engine also drives a shaft parallel with the screw, which gives motion to a hoisting winch at the other end of the bed-plate. There is a three-sheaved pulley-block for heavy lifts and a single-sheaved block, or "whip," for light loads. The proof load of the structure was 100 tons. On the model are given particulars of many other sheer legs of this type. M.1064.

990. Model of hydraulic sheer legs. (Scale 1 : 25.) Made by Monsieur P. Regnard, 1899. Plate XII., No. 3.

This lifting appliance was designed and constructed by the Compagnie de Fives-Lille in 1887 for the Port of Marseilles.

The equal legs are built-up box girders 3·28 ft. sq. at the middle, tapering to 1·64 ft. sq. at the ends; the effective length of each is over 110 ft. The back leg is similarly constructed, but its lower end is carried in guides, inclined at 53 deg. with the horizontal, formed on two large plate-frames built in the engine-house and bolted down to a concrete foundation. Between these guides is a crosshead connected by a piston rod 7·48 in. diam. with the piston of a hydraulic cylinder 21 in. diam. and 22·7 ft. stroke, by which the heel of the back leg is controlled. By the movement thus permitted a horizontal travel of the load through a distance of 46 ft. is obtainable; the maximum overhang from the quay wall is 30 ft.

The load is lifted by a direct-acting hydraulic cylinder, 21 in. diam., with a piston rod 7·5 in. diam. and a stroke of 43 ft. This cylinder is hung by two side rods, in order that the weight of the load shall not be taken by the metal of the cylinder; a safety device is also provided consisting of two racks attached to the piston rod crosshead and fitting in stirrup-shaped pawls fixed to the cylinder. The mechanism for moving the back leg is similarly fitted with safety racks. On the back leg is placed a small hydraulic cylinder multiplying eight times, and giving a travel of 46 ft. for use in lifting slings and other light loads not exceeding 8 tons; the fixed end of the chain from this jigger is secured to a double-geared winch, by which arrangement the position of the lifting hook can be quickly adjusted.

Water, at 710 lb. pressure, is supplied by the accumulator shown, which is fed by a direct-acting pumping engine and controlled by valves in the engine-house, but the lifting is controlled from an elevated platform; the water connections with the hydraulic cylinders are made by swivelling pipes, which, with the rest of the service, are 2·95 in. diam. With the accumulator pressure the maximum load that can be lifted is 75 tons. For greater loads this pressure is intensified by the horizontal direct-acting hydraulic pumps shown, which have pistons 13·19 in. and 9·84 in. diam. respectively, with a stroke of 3·28 ft. and a common trunk 9·56 in. diam.; by these a pressure is obtained sufficient for lifting the maximum load of 120 tons, while on test a load of 140 tons was dealt with. This arrangement is also reversible, so as to economise accumulator water when lifting loads of less than 25 tons.

The leading dimensions of the structure are:—Height of lift, 46 ft.; height of lift above quay, 22·9 ft.; lateral spread of front legs, 36 ft.; distance of heel of legs from edge of quay, 3·9 ft.; effective length of front legs, 110·5 ft.; effective length of back leg, 109·9 ft.; horizontal travel of apex, 46 ft.; volume of water used in a lift of 46 ft., 112 cub. ft.; volume of water used in traversing through 46 ft., 55 cub. ft.; test load, 140 tons.

M.3060.

991. Model of travelling crane. (Scale 1 : 4.) Received 1877.

This shows a form of "accident" or "breakdown" crane for use in clearing an obstructed portion of a railway; in its general arrangement, however, it resembles a crane built in 1806 by Mr. Peter Keir for the Ramsgate harbour works.

A four-wheeled truck, of standard gauge and fitted with brakes, supports the crane post and a roller path; and the whole of the frame, including the post and jib, are of timber. The jib is capable of making a complete turn, while a backward extension of it carries a platform for the men working the crane, and also two rails along which a counterbalance-weight, mounted on wheels, can be traversed by a small winch, so that its leverage can be increased when a heavy load is being lifted. The load is raised by a double-purchase

winch worked by two men; the slewing is done directly without the aid of mechanism and, as the counterweight turns with the jib, the balance, once established, remains undisturbed.

The radius of the jib circle is 11·5 ft.; the wheel base is 5 ft.; the counterbalance weighs 0·5 ton, and the maximum load that can be lifted is 2 tons. M.2528.

992. Model of a travelling crane. (Scale 1 : 15.) Presented by Capt. F. Fowke, R.E., 1859.

This represents a travelling gantry employed by M. M. Nepveu & Cie., for the temporary work of erecting machinery in the Paris Exhibition of 1855. The four wheels upon which it runs are free to turn like ordinary castors, so that it can be moved in any direction on a flat floor. M.1761.

993. Model of travelling steam crane. (Scale 1 : 8.) Lent by Messrs. Joseph Booth & Bros., 1900.

This type of crane travels on ordinary rails and is capable of lifting and carrying loads of from 1 to 5 tons without any holding down, the weight of the boiler, etc., sufficiently counterbalancing the load; the model represents a 3-ton crane for travelling on rails of the standard gauge.

The power is exerted by two vertical steam cylinders, fitted with link motion reversing gear, which drive a horizontal crankshaft provided with clutches and gearing by which the power can be transmitted to the various mechanisms for travelling, slewing, raising the jib, and lifting the load. The crane base is a four-wheeled truck carrying a circular race upon which the weight of the machinery and load is supported by three rollers, while the interior of the race forms the spur ring that is utilised when slewing.

M.3129.

994. Photographs of steam cranes. Presented by T. Smith, Esq., 1892.

The travelling crane, for lifting weights up to 16 tons, runs on the ordinary permanent way and fits other rolling-stock. The engine has two double-acting cylinders, from which clutches and gearing all movements of the crane can be obtained. The large chain barrel gives a great range of lift, and the curved form of the braced jib adds to the available height above the rails.

The travelling crane for ship-yards is intended for lifting a load of 10 tons at a radius of 20 ft., or 7 tons at 25 ft. from the centre post, the radius being variable. It is propelled and all other motions are given by two cylinders 8·5 in. diam. by 12 in. stroke, receiving their steam from a Nicholson boiler 8 ft. high by 4·5 ft. diam. The form of trussed jib gives the head-room of the curved type while directly meeting the stresses. The total weight of the machine is 50 tons, and it hoists by a steel wire rope 1·125 in. diam.

The overhead travelling crane has a span of 50 ft., and will lift a weight of 75 tons through a height of 30 ft. without the lifting rope overlapping. Steam at 80 lb. pressure is supplied by a 9 ft. by 4·5 ft. diam. boiler, overhanging the crab on one side, and partly counterbalanced by the water tank on the other. The engine has a pair of diagonal steam cylinders 9·5 in. diam. by 14 in. stroke, and is connected for the various motions by double cone friction clutches; the motion to the longitudinal travelling wheels is transmitted through the square shaft. The steel wire lifting rope is 6 in. circumference, and runs in four plies round grooved sheaves in the top and bottom blocks, but the gearing is arranged to give three different speeds for hoisting. M.2452.

995. Model of block-setting "Titan." (Scale 1 : 24.) Lent by Messrs. Stothert & Pitt, Ltd., 1905.

This represents a crane designed by Mr. W. Matthews and constructed by Messrs. Stothert & Pitt in 1891, for use in setting the concrete blocks composing the piers of the Admiralty Harbour, Peterhead, Scotland. It lifts a maximum load of 50 tons at a radius of 100 feet. Such cranes were introduced about 1869, and they have since been developed to the form shown. They are designed to set all the blocks in advance of the machine, which itself rests on the finished portion of the work, thus dispensing with staging.

The structure consists of two counterbalanced cantilevers 160 ft. long with 82·75 ft. overhang, placed 9 ft. apart and built as box-girders, 11 ft. deep at the centre, tapering to 4 ft. at the front ends. These are braced together at the centre and ends only, and form the jib along which travels an eight-wheeled truck or "jenny" carrying the load. The tail end of the jib supports the driving machinery and ballast tanks. The cantilevers rest on, and are rigidly braced to, a circular box-girder ring which is supported by 52 conical rollers resting on a lower ring which forms part of the truck or running carriage. The crane runs on two tracks 31 ft. apart, one being of the standard gauge laid on the road, and the other of 3·17 ft. gauge placed on the parapet about 11 ft. higher. The high side of the truck is built as a lattice girder and the lower side as a single box-girder, while across these are placed four box-girders which support the lower rolling ring. The truck is mounted on 32 wheels spread over a wheel base of 34·5 ft. and the journals are fitted with springs. The jib is secured by a central pivot and is slewed by a large toothed ring; large hook brackets are provided for safety, but the centre of gravity of the whole superstructure always falls within the roller path.

The load is lifted by an eight part steel wire rope which is reeved double in two parallel portions, so that two parts are coiled round the barrel, and there is an equalising pulley at the end of the cantilevers. The blocks are attached by two lewis-bars having hinged loops at their upper ends which hook over the ends of a swivelling cross beam attached to the pulley block. The lifting drum is 8·5 ft. diam. and is provided with brakes for lowering; the racking and slewing motions are worked from shafting, and a vertical shaft, passing through the centre pin, drives the running wheels by pitch chains and gearing. Steam is supplied at 70 lb. pressure by a vertical boiler to a pair of engines having cylinders 12 in. diam. by 19 in. stroke, which actuate the whole of the motions.

The crane weighs about 350 tons and its test load was 62·5 tons.

M.3404.

996. Model of combined crane and locomotive. (Scale 1 : 8.) Received 1896. Plate XII., No. 5.

The locomotive is a small four-wheeled coupled tank engine with outside cylinders and Joy's valve gear. The tanks and coal bunkers are at the sides; there is a screw brake, and the buffer beam is fitted with large heads so as to suit a variety of trollies and trucks.

The crane consists of a single jib carried on a swinging fulcrum, having its inner end controlled by guides secured to a top ring that is supported on an upward extension of the circular external firebox. The end of the jib is pulled downward by the piston rod of a vertical direct-acting steam cylinder, the motion of which is thus magnified. The jib has three hooks to it, for dealing with loads of 2, 3, or 4 tons at distances from the centre of the railway of 20, 16, and 12 ft. respectively; the weight of the jib and part of the load are balanced by a counter-weight attached to the top ring. The load is slewed by a three-cylinder engine, which, by worm and spur gearing, rotates the top ring that carries the jib, etc.

M.2950.

997. Model of rope-driven overhead travelling crane. (Scale 1 : 12.) Made in the Museum from drawings supplied by Messrs. Cowans, Sheldon & Co., Ltd., 1911.

An overhead travelling crane, driven by an endless rope, was patented by David Mollard in 1794, and such cranes, worked directly by hand, were gradually developed during the early part of the 19th century. Power driving from stationary steam engines was introduced about 1850, and with this arrangement high-speed rope transmission was very largely used for about 40 years, when it was superseded by electrical transmission.

The model represents a crane constructed in 1892 by Messrs. Cowans, Sheldon & Co.; it was one of the last of this type made by the firm. It consists of a travelling bridge made up of two 14 in. by 6 in. rolled joists connected by two end carriages built up of channel irons and plates; this is mounted on four wheels running upon rails which are carried 18 ft. above the ground by girders supported upon columns. One wheel of each carriage is a driving wheel, and these are connected together by gearing and shaft which is supported by bearings attached to the bridge. The crab carrying the lifting gear is mounted on four wheels and runs on rails laid on the bridge girders; its lifting and traversing motions are obtained, through spur and bevel gearing, from two feather shafts erected parallel to the rails and passing through keyed sleeves attached to the crab. Double-armed tumbler bearings support these shafts and are turned over by a striker on the crab as it passes them.

One of the end carriages has a cast iron frame bolted to it and this carries the driving pulleys, clutches and gearing for the three motions of the crane. There are three rope pulleys, one for each motion, mounted on short shafts that carry at their centres bevel wheel reversing gears with double-cone clutches. The lifting gear has an intermediate shaft, upon which is fitted a brake drum and strap for controlling the descent of the load; the brake and the three clutches are manipulated, through hanging chains, by a man standing on the ground below the crane. The lifting chain has its two ends fixed to the drum and passes round a sheave attached to the hook; it is guided on the drum by right and left-hand grooves, so that the lift is vertical.

The endless driving rope is of hemp, 1·25 in. diam., and travels at a speed of 2,500 ft. per min.; it passes round pulleys 3 ft. diam., placed beside one of the crane travel girders, so that the upper side of the rope may pass round the pulleys on the crane. The rope-driving pulley is supported on wall brackets, and is driven by a belt with fast and loose pulleys from a shaft below the floor level; the tension of the rope is maintained by a hanging pulley loaded with weights. In practice the long length of rope between the end pulleys would be supported by small guide pulleys.

The span of the crane is 22 ft. and its load 3 tons. The hoisting speed is 18·7 ft. per min.; the crane travels at 93 ft. per min., and the crab at 51·5 ft. per min.; the h.p. required is about 20. M.3905.

998. Model of electric overhead travelling crane. (Scale 1 : 12.) Made in the Museum from drawings supplied by Messrs. Herbert Morris & Bastert, Ltd., 1908. Plate XLI., No. 6.

During recent years, owing to improvements in electric motors and the reduced cost of electrical energy, electrically driven overhead travelling cranes have been extensively introduced. Such cranes are more economical and convenient than the older ones in which the power was transmitted by means of square shafts, belts, or ropes, and which absorbed energy when not actually in use. In the earliest electric cranes of this type one motor was employed and the various hoisting, traversing, and travelling motions were derved from it by means of gearing and clutches, but it has been found more convenient to employ a separate motor for each motion; this arrangement, though involving a greater initial cost, permits of a higher average speed and ensures a saving in current and repairs.

The three-motor crane represented was constructed in 1903 by Messrs. Herbert Morris & Bastert, Ltd., and consists of a travelling bridge across which a crab carrying the lifting gear moves. The bridge has two steel I section girders, 15·75 in. deep, which are stiffened by channels at the top and connected by two end-carriages built up of channels and plates. It is mounted upon four tram wheels running upon overhead rails, which are carried by girders supported by the masonry of the building, or by columns. Two tram wheels are carried by each end-carriage, and the front pair, which constitute the driving wheels, are connected by spur gearing and shafting with a motor from which the main travel motion is derived. This motor is placed near the middle of a platform in front, which is supported by an auxiliary lattice girder. The shafting is fitted with a mechanical brake actuated by a foot lever in a cage, which carries the operator and is suspended underneath one end of the platform.

The crab carries two motors, one of which drives the lifting mechanism whilst the other actuates the cross traversing motion of the crab itself. The hoisting motor is connected with a rope drum by toothed gearing, and on the motor shaft there are two brakes, one magnetic and the other mechanical. The magnetic brake automatically comes into action whenever a current is not passing through the hoist motor. It is controlled by a solenoid, which is included in the motor circuit and raises a core connected with levers carrying a counterweight, so arranged that when no current is passing, a friction band brake is brought into action by the descent of the weight. The mechanical brake sustains the load at all times, and consists of a bronze coil through which the power is transmitted. The coil is contained in a drum and when lowering it rubs against the inside of the drum, the latter being then held stationary by pawls engaging with a ratchet wheel. Lowering is consequently only possible when the motor drives the gearing in opposition to the retardation of this brake. Either of the brakes is sufficient to sustain the load, and the magnetic brake also prevents the inertia of the moving parts causing the load to rise after the current has been cut off from the motor. The crab is mounted upon four tram wheels running upon rails carried by the bridge girders, and two of the wheels are secured to a driving axle which is connected by toothed gearing with the traversing motor.

The bottom block swivels on a ball bearing and has two sheaves, from which portions of a steel wire rope pass to right- and left-handed grooves at the opposite ends of the rope drum while the intermediate portion of the rope passes round a compensating sheave carried by a girt connecting the crab sides, a true vertical lift being thus obtained. Overwinding is prevented by a cut-out switch, which is mounted on the front crab side, and is actuated by a pinion on the drum shaft, intermittent gearing, a cam, and levers, which are not shown on the model.

The bare wires carrying the main current are situated inside one of the longitudinal girders and are carried by brackets built up of angles. They are insulated by globe strain insulators and kept in tension by means of drawbar eye bolts and spring washers. The current is collected by contact shoes mounted upon hanging sleeves, and led to the operator's cage from where it is distributed to the motors. There are eight trolley wires for the crab motors, three inside each of the bridge girders and two outside the back girder, the arrangements for carrying these wires and collecting the currents being similar to those for the main wires. The motor-controllers, resistances, fuse-board, and a switch are placed in the operator's cage.

The crane was designed for a load of 5 tons and a continuous current supply at 500 volts. It has a span of 28 ft., and the approximate operating speeds are:—Hoist, 25 ft. per min.; cross traverse, 100 ft. per min.; main travel, 300 ft. per min. The motors are series wound and of the following ratings:—Hoist, 13 h.p.; crab traverse, 2 h.p.; and main travel, 8 h.p. M.3584.

999. Model of 50-ton floating crane. (Scale 1 : 24.) Lent by Messrs. Hunter and English, 1896. Plate XII., No. 4.

This crane, constructed in 1885 on a system patented by Mr. Walter Hunter, is employed at the Tilbury Docks in performing similar lifting work

to that done by sheer legs, but without being stationary or requiring that the loads be brought to it.

The crane itself rests upon steel rollers running upon a curb, 26 ft. diam., supported on a wrought iron cylinder, built into the supporting hull and secured by bulkheads to its sides; the centre of the crane is over the centre of the hull. The jib consists of two tubular steel members, and the framing of the crane is of wrought iron; it contains at the back a chamber holding cast-iron kentledge blocks that counterbalance the weight of the overhanging jib. The load being lifted is counterbalanced, so as to keep the hull level, by a weighted wrought iron truck weighing 130 tons and running upon rails along which it is traversed by power. When a load to be lifted is properly slung the lifting engines are run until a slight list is given to the hull; the balance-weight is then moved out until the hull is again level. The lifting can then be proceeded with, and any slewing done without disturbing the even trim of the hull.

The lifting engine consists of a pair of horizontal 12 in. by 12 in. cylinders, and drives a 36-in. diam. hoisting barrel by worm gear. The steel rope is 6 in. circumference, and the moving block has in it three sheaves 36 in. diam. The lifting engine also slews the crane, by friction clutches and spur gear, that drive a pinion engaging in a fixed circular rack 14·6 ft. diam. The balance truck is moved to and from the centre by two long screws, which are driven by bevel gear from a small Willans three-cylinder engine.

The vessel is propelled by twin screws 5 ft. diam. by 6·5 ft. pitch, driven by two compound engines with 9 in. and 18 in. cylinders by 18 in. stroke, indicating collectively 160 h.p., and giving a speed of four knots.

Steam for all purposes is supplied by a return tube multitubular boiler 8 ft. diam. by 8·6 ft. long, with 78 tubes 3 in. diam. To the engines on the crane the steam is conveyed by a swivel pipe in the crane centre, and the exhaust is led through an annular pipe to the surface condenser, which has independent air and circulating pumps.

Length of hull, 110 ft.; breadth, 44 ft.; depth, 9 ft.; height of deck above water level, 3·5 ft.; radius of lift, 47 ft.; length of jib between centres, 91 ft.; effective lift from water level, 70 ft. M.2964.

1000. Model of floating sheers. (Scale 1 : 48.) Received 1913.

These sheers were constructed in 1890 for H.M. War Office by the Thames Ironworks' Shipbuilding and Engineering Co.

The hull, which is of steel, is constructed with water ballast compartments at each end, and a centrifugal pump is provided to pump water from one to another as the load to be lifted requires, so as to keep an even keel. The sheers are built up of riveted posts tied back by eyebar links to the hull structure. Lifting is effected by a compressed steel hydraulic ram and cylinder incorporated with the end of the sheers. A pair of duplex hydraulic pumps supply water at a pressure of one ton per sq. in.

Length of hull, 114 ft.; breadth, 44 ft.; depth, 12 ft.; lifting capacity, 250 tons; total weight of hull and machinery, 400 tons. Inv. 1913–303.

Lifts and Elevators.

1001. Model of a continuous elevator. (Scale 1 : 8.) Contributed by the Commissioners of the Great Exhibition, 1851.

This endless chain elevator was patented by Mr. John Spurgin in 1837, and is intended for lifting bricks and mortar to the top of a building in course of construction. The top drum has the shaft prolonged for the purpose of driving. Studs, to which buckets were attached, project from the chain. M. 509.

1002. Model of a power lift. (Scale 1 : 8.) Presented by the Rev. Dan. Greatorex, B.D., 1895.

This model shows a form of lift introduced by the donor in 1851. It is designed for working by hand or from running shafting, and is shown arranged in a building of three floors, the detailed construction of which is represented, as well as the method of forming the well-hole, through which the cage of the lift works.

The cage is guided by four vertical timber guides, and is supported by two ropes, attached to a wrought iron forging, from which four tie-rods descend to the floor of the cage. The ropes pass over two V-grooved pulleys overhead, and then connect with a pair of balance-weights which work in guides at the back of the well-hole. Three lifting ropes have been provided for, but the central one has probably never been fitted.

When working by hand power, the operator pulls at one side of an endless rope passing over a large V-grooved pulley on a shaft of the overhead gear; on this shaft is a pinion, gearing with a large spur wheel on the main shaft. For more quickly lifting light loads, a second wheel and pinion of less ratio are introduced, and a claw clutch, which can be operated by a vertical rod that passes through all the floors, enables this change gear to be operated from any level.

For driving by power, a single belt pulley loose on the countershaft is provided, which can be thrown in by a clutch similarly controlled; the lowering is performed by gravity under the control of a strap brake arranged on the main shaft. This brake is operated by a vertical rod on the right-hand side, controlled by hand wheels on every floor, or by an endless rope that passes through the cage. M.2737.

1003. Model of automatic tipping lift. (Scale 1 : 12.) Lent by Sir Hay F. Donaldson, K.C.B., 1896.

This lift, patented in 1895 by Sir Hay F. Donaldson, is used at the cold storage depôt at West Smithfield for taking frozen meat from a receiving staging and delivering it on any of the five floors of the building. The two lifts there fitted are worked by hydraulic rams, and were constructed by Sir W. G. Armstrong, Mitchell & Co.; each is capable of lifting thirty carcasses to a height of 50 ft. in one minute.

The method of working is as follows:—The carcasses having been stacked upon the platform or tray, the attendant pulls over the lever controlling the points of the floor at which the meat is to be delivered. When these set points are reached, the platform tips and stops automatically; the carcasses then slide on to a shoot that delivers them to other inclined shoots leading directly into the chambers. M.2954.

1004. Diagrams of hydraulic lifts. Lent by E. B. Ellington, Esq., 1891.

Hydraulic lift balance:—In a long-stroke direct-acting hydraulic lift the size of the ram is determined entirely by its stability as a column, so that unless overhead pulleys and counterbalancing weights and chains are introduced, the consumption of high-pressure water by such lifts becomes prohibitive. The hydraulic balance invented by Mr. Ellington, however, counterbalances the weight of the cage and the ram, and thus reduces the consumption of water to that necessitated solely by the capacity and speed of the lift. This is effected by placing the water in the lift cylinder in direct communication with that in a weighted hydraulic cylinder of moderate stroke, so loaded that the permanent weight of the cage and its ram is balanced to the required degree; this water, however, merely acts as a fluid connection between the two cylinders and is not consumed. To cause the lift to ascend, the load on the hydraulic cylinder is increased by the downward pressure of a ram under the action of water from the power mains, the water used in giving this added pressure representing the consumption in the upward travel of the cage.

In another arrangement represented, the counterbalance load is put on by low pressure water from an elevated tank, so that as the lift ram goes up, the increased load due to its lost displacement, or flotation, may be partly compensated for by a greater head on the balance ram.

Suspended lift:—This is worked by a long-stroke vertical hydraulic cylinder with a differential ram, the portion passing through the upper part of the cylinder being 2·5 in diam., while the lower one is 6 in. In this way long-stroke rams of sufficient stability can be economically employed, whatever the water pressure, since the effective area is only an annulus; the weight of the cage is counterbalanced by that of the ram, assisted by added weights if necessary. M.2384.

1005. Model of a hydraulic balanced lift (working). Lent by Messrs. R. Waygood & Co., 1891.

This represents a direct-acting hydraulic lift, in which the weight of the cage and ram is balanced by an arrangement known as the hydraulic balance, by which the use of overhead chains and attachments is avoided.

The cage is guided in its course by two circular wrought iron guides, and the weight is borne by a solid steel ram built up in lengths by screwed joints. The ram works in a vertical cylinder sunk in the ground and fitted at the top with the usual stuffing box and packing. The upper part of the cylinder communicates with the cylinder of the hydraulic balance, which consists, in this example, of a lower cylinder fitted with a ram, from the top of which projects a flange, from which two tie-rods descend to a heavy balance-weight below, so that the pressure on the ram supports these weights, and this pressure is nearly equivalent to the hydraulic pressure of the cage and ram.

Inside the ram of the balance fits a smaller stationary ram, so that when water under pressure is admitted to this ram its effect is to increase the pressure on the water in the hydraulic balance, and so force up the cage and its load. The water connecting the balance with the cage simply passes backwards and forwards when the machine is being worked, the water actually used being that which enters the upper ram of the balance. The water, in the model, is supplied by a hand force-pump, fitted with a safety and relief valve, but in practice it would be supplied from an independent accumulator, or from a public supply of water, preferably at high pressure. The balance cylinder may be used as an accumulator, and some of its water be employed as pressure water by letting it into the upper ram. M.2368.

1006. Model of hydraulic lift (working). (Scale about 1 : 8.) Lent by the Hydraulic Engineering Co., Ltd., 1904.

This represents a simple direct-acting hydraulic lift in which the weight of the cage and its load are overcome by the pressure of water exerted upon a ram working in a vertical cylinder arranged at the bottom of the well-hole, the stroke of the ram being equal to the total lift required.

The cage is guided by two circular steel rods secured to the lift shaft near opposite corners, and the ram, which is built up of steel rods screwed together, is attached beneath the floor of the cage by a ram-head which distributes the effort. The cylinder of the ram is in lengths connected together by flange joints and is accommodated in a bore-hole sunk below the lift shaft. The top of the cylinder has usually a gland packing, and at its sides are spring buffers to absorb the shock should the lift be lowered too rapidly at the end of its travel.

The admission and discharge of the water are controlled by a valve actuated by the attendant in the cage through a rope, but in the model special arrangements are introduced for the purpose of insuring that the lift shall not be started before the doors are closed, and that no door leading into the well-hole shall be open except that at which the lift is standing; also to give automatic stopping. The valve is actuated by a triple vertical rod, one member of which passes through the cage, to be operated by hand, another

beside it, and the third outside the shaft. The doors are locked by bolts, which are withdrawn by the cage as it comes opposite them, and each is also provided near its hinge with a small curved arm which, when the door is opened, enters a notch in the front valve-rod and thereby secures it. The other valve-rod is provided at intervals with special projections, by which the lift may be automatically stopped at any intended floor.

The water, in the model, is supplied by a hand pump, but in an actual lift would be obtained from an accumulator or from the mains, while a hydraulic balance would usually be interposed to compensate for the absence of counter-weights. M.3356.

1007. Elevator chains. Lent by Messrs. Hans Renold, Ltd., 1913.

These are examples of Renold block chains adapted for use with elevators.

The blocks are cut from steel bar of the correct section, and the side links punched from steel plate; they are secured together by shouldered rivets in the usual way. Where buckets are to be attached, the side links are replaced by special links having projecting flanges to suit the buckets. Several examples of medium and long pitch-chain, varying from 2·62 in. to 6 in. pitch, are shown, as well as other examples with different forms of bucket attachment.

Three examples of chains with buckets attached are shown also. The largest has two strands of chain, 4·5 in. pitch, each having a breaking strength of 14,000 lb.; it has riveted buckets suitable for elevating grain in special telescopic elevators from the holds of ships. The second example has a single chain, 3·125 in. pitch, with a breaking strength of 5,900 lb., and is fitted with stamped buckets for raising wet materials in vertical elevators at high speeds. The third example has two chains of the same size as the second, but is fitted with buckets for lifting lumpy materials, such as coal, at low speeds on inclined elevators. Inv. 1913–3 to 8.

TRANSMISSION OF POWER.

With the introduction of the rotative steam engine in the last quarter of the 18th century the transmission and subdivision of power, hitherto but little required owing to the smallness of existing prime movers, began to assume importance.

Shafting, Bearings, and Couplings.—In the steam engine cast iron shafts, often square in section to facilitate the attachment of wheels by "staking," were substituted for the earlier round or polygonal hooped wooden shafts then in use. Later, wrought iron was introduced because it permitted higher speeds; and now mild steel is employed, resulting in a still further economy in weight. Shafting, although convenient, is probably the least efficient means of transmitting power.

The bearing, at first a simple box, was improved by the provision of renewable brass steps to take up wear and reduce friction. A cap with bolts, the lining of the steps with anti-friction metal, first brought out in 1839 by Isaac Babbitt, and means for horizontal and vertical adjustment, cover most of the features of the plain bearing. To reduce friction further, the method applied to clocks by Henry Sully about 1720 may be instanced. This consisted in supporting the pivot on the peripheries of narrow wheels of comparatively large diameter. The more generally applicable method of interposing a number of small rollers between the journal and its box was patented in 1787 by John Garnett (*see* No. 1014). Sliding friction was not altogether eliminated, however, and it is only within recent years that such bearings have been rendered satisfactory for heavy loads (*see* Nos. 1016–20). Ball bearings, although proposed in the 18th century, received their first application of importance from 1876 onwards in cycle construction (*cf.* No. 785), where loads are small and speeds low. Since then their use has been gradually extended to heavy loads and speeds up to 4,000 rev. per min. These advances in the use of both roller and ball bearings have been rendered possible by the adoption of new materials and by the development of machine tools, which has enabled the component parts to be manufactured commercially with the necessary high standard of accuracy (*see* Nos. 1021–5).

Fixed shaft couplings are sometimes of the muff type (*see* No. 1028), but oftener of the flange type. To allow of slight error in alignment or for insulation purposes the flexible coupling is used (*see* Nos. 1029–31). To engage one shaft rapidly with another, one half of the coupling is made to slide axially. At slow speeds the claw clutch is suitable, but for high speeds shock is minimised by frictional engagement, for which the cone and the expanding clutch are very convenient (*see* Nos. 1037 and 1039), but many other applications have been made.

Gearing.—This can be divided conveniently into four main groups, viz., toothed, belt, rope and pitch-chain gearing.

Toothed gearing is confined to positive transmission at short range. Spur and bevel wheels in very early times were built up in wood with mortice teeth, or, in the case of pinions, with round rungs. Mortice teeth are still retained for special duties, although wheels wholly of cast iron were introduced in the 18th century. The tooth shape was mostly empirical, leading to inaccuracies which caused noise and friction. With teeth correct in outline and machined from the solid, even worm-gearing gives high efficiency (*see* No. 1048).

With belting, power is transmitted solely by frictional contact, hence slip or creep occurs, and the drive is not positive. For shafts at short distances apart and a speed ratio of not more than 6 : 1, it is greatly used. Belting is generally of leather, but the high cost has led to the employment of fibres or hair combined sometimes with india-rubber. Wide belts transmit less than narrow and long belts more than short ones per unit width. The speed of main belts should be about 3,500 ft. per min.

Rope gearing is employed like belting (*see* No. 1060, etc.), but shafts may be as much as 100 ft. apart. It is used therefore in mills and factories, for which purpose it was introduced in 1856 by Mr. J. Combe. Cotton is the material now employed for ropes, ranging from 0·75 in. to upwards of 1·75 in. diam., and at speeds between 4,000 and 5,000 ft. per min. Wire rope, supported intermediately, is used for still greater distances and for more exacting services, *e.g.*, for mine haulage (*see* No. 1057) and cable traction. Diameters, varying from 0·5 in. to 1·5 in. are used. For all kinds of ropes, the pulleys must be ample in diameter.

Pitch chains have the advantages of belting with the positive transmission of toothed wheels. Simple block chains were used in clocks and in textile machinery in the 18th century. Development began with the roller chain invented in 1864 by Mr. J. Slater. The improved bush form was brought out in 1880 and the "silent" chain with projecting teeth in 1895 by Hans Renold (*see* No. 1068). These improvements in construction, rendering pitch chain efficient and equal to any duty, have led to great extension of their use even in place of belt and spur gearing.

Fluid Pressure.—Hydraulic power transmission was schemed by Bramah in 1802, but was not carried into effect till 1846 when Lord Armstrong constructed the first multiplying hydraulic crane at Newcastle quay (*see* No. 986), but the system did not become generally applicable till the invention of the hydraulic accumulator in 1851 (*see* No. 1073). When it is realised, for example, that 2 gal. of water per min. at a pressure of 700 lb. is equal to 1 h.p., the value of public supplies such as are now to be found in many cities will be obvious. Manchester has a pressure of 1,120 lb., and there is no reason why a pressure of 1 ton per sq. in. even should not be distributed with economy.

Power was transmitted by compressed air early in the 19th century at Soho by William Murdock. The method has been adopted extensively in mining and tunnelling where the exhaust from the motors is of value for ventilation. Its efficiency decreases rapidly as the pressure employed is increased, owing to losses through thermal changes in compression and during expansion.

Shafting.

1008. Model of shafting and supports. (Scale 1 : 15.) Presented by Capt. F. Fowke, R.E., 1859.

This represents the ornamental standards and lattice girders used in the Paris Exhibition of 1855 for supporting the shafting for driving the machinery in motion. The girders, besides supporting the intermediate bearings, formed a gallery, by which the attendant could obtain access to all the bearings for the purpose of oiling without the use of ladders. M. 1760.

1009. Stow's flexible shafting. Received 1890.

This arrangement was patented by Mr. N. Stow in 1874. The shaft is shown complete with driving gear as fitted for working a portable drill. From the overhead countershaft the power is transmitted by a rope to the flexible shaft, a hanging double sheave block enabling large variations to be made in the virtual length of the rope according to the position of the work. When so great a range is unnecessary it is better to dispense with the hanging sheave block by running the rope directly from the countershaft to the flexible shaft.

The flexible shaft resembles a short length of steel wire rope, and is carried in a leather sheath with a protecting lining of wire. A spare shaft is shown withdrawn from its sheath. This shaft is intended for driving metal drills of from 0·5 in. to 0·625 in. diam., when its speed is about 600 rev., but when wood boring the speed of the shaft is 1,500 rev. per min. The gearing at the portable drill reduces these speeds in the ratio of 4 : 1, but when driving a portable grinding apparatus such a large reduction is not made. M.2297.

1010. Flexible shaft. Lent by Messrs. Charles Wicksteed & Co., Ltd., 1907.

This is a portion of a flexible shaft of the form patented by Mr. C. Wicksteed in 1904 for transmitting power to portable tools.

It consists of a number of short pieces of shafting connected together by universal joints and running inside a flexible metallic tube which may be filled with oil. The shaft is supported within the tube by a ball-bearing collar at each joint, and these come into contact with the tube when it is bent, thus allowing the shaft to rotate with little friction. The end of the shaft is provided with a dog clutch, and the tube with a bayonet joint coupling, for attachment to the tools. M.3515.

Bearings.

1011. Journal bearings. Presented by Messrs. J. Woods & Co., 1864.

These brass steps are lined with babbitt metal, an alloy of tin and antimony, possessing the property of creating but little friction or wear on a journal turning on it, if suitably lubricated. Such anti-friction alloys are however, too soft and weak to withstand the pressures experienced, and so are supported by being surrounded by gunmetal except on the bearing surface.

One example is a bearing or step for a locomotive axle, and this has a curved exterior to insure equal longitudinal pressure. The other is a lined brass for a small crankpin, which, to permit of additional freedom, is slightly spherical in form. M.2517.

1012. Bearings for shafting. Lent by Messrs. Croft and Perkins, 1892.

Two systems of self-adjusting bearings are here shown. The object in both cases is to secure that the bearing shall fit the shaft uniformly over its length, and that any settling in the supports shall, by the self-adjusting arrangement, be prevented from causing serious binding. In one case the cast iron bearings in halves are each provided with a spherical projection, and the bearing is held in its bracket by two large screws with recessed heads, so that a ball and socket joint is obtained. In the other arrangement, patented by Mr. W. R. West in 1889, brasses are employed, and are carried in a plummer-block with a long cylindrical tail-piece, which is carried in a bored T arm with a smaller tail-piece, which is again carried in the bored bracket. The complete arrangement permits of automatic adjustment by rotation round two axes at right angles, while these sliding tails, being secured by set screws, give a ready adjustment in two directions. The pulley shown is built up, having a cast iron boss and wrought iron arms and rim, but the rim is made of a section giving extra thickness in the middle where the arms are attached. It is a split pulley with a slightly tapering bore, and is secured to the shaft by a corresponding bush which is cut into three pieces, the object being to permit of the pulley being readily fitted to a shaft of a different diameter by simply substituting a fresh bush. M.2481.

1013. Hanger for shafting. Lent by the Hoffmann Manufacturing Co., Ltd., 1912.

This hanger, embodying a swinging housing and a self-contained swivelling ball bearing, thus permitting great freedom to the shaft, was patented in 1910 by Mr. O. A. Schmidt and the firm.

It consists of a cast iron housing hinged on a spindle suspended by three eye-bolts from a convenient bracket; the nuts allow of vertical adjustment. The housing has a spherical seating to accommodate a ball bearing of the type shown in No. 1021, in which the ball race is held on the shaft by a tapered slotted sleeve, tightened by a nut. The bearing is enclosed to keep out dust, etc. To insert it in the housing it is dropped in on the side where the two slots are and then turned through a right angle. To prevent the shaft swinging endways, one eye-bolt on one of the hangers has an extension to take a set screw, which enters a projection left on the side of the housing.

By the provision of a base-plate instead of the eye-bolts the hanger is transformed into a pedestal.

A number of sizes are made, the one shown being for a shaft 2·25 in. diam. M.4110.

1014. Early roller bearings. Watt Collection, 1876.

The method of minimizing the friction of a journal by giving it a bearing on the peripheries of narrow wheels was applied to clocks about 1720, but is not so generally applicable as is the method of interposing a number of small rollers between the journal and its bearing as here shown.

A horizontal shaft carrying a flywheel is supported in bearings stamped "Garnett & Co., No. 1 Patent," the specification of which, dated January 6th, 1787, was granted to John Garnett of Bristol. Each bearing has six rollers revolving on pins fixed in two end rings, which are held apart by three distance pieces riveted over to form a cage, which is held in place by a wire ring sprung into a groove in a retainer which has a spherical exterior to admit of errors in alignment. This retainer has a removable dovetailed piece to allow it to be inserted in place in the plummer-block.

The shaft is 0·5 in. diam.; the rollers are 0·375 in. diam. by 0·56 in. long. M.1815.

1015. Roller bearing sheave. Presented by the Admiralty, 1864.

This sheave for a ship's block is bushed with another of Garnett's roller bearings (*see* No. 1014). The only differences in construction are that the ends of the rollers are turned down to take bearings in the end rings, and that there is no spherical container. In another modification a groove was turned in the middle of each roller and a washer notched to suit was used to hold them in position; in this there is the liability to cross-winding and in both there is still sliding friction. These disadvantages and the unsuitability of the materials employed coupled with the then low standard of accuracy restricted these bearings to light duties such as that shown. A manufactory was started and the bearings were made in large quantities.

The sheave is 7 in. diam., the arbour is 0·75 in. diam., and the six rollers are 0·625 in. diam. by 0·875 in. long. N.1010.

1016. Roller bearing. Lent by Messrs. Broom and Wade, Ltd., 1913.

The rollers in these bearings are of the hollow and flexible construction patented in 1892 by Mr. J. W. Hyatt; it is unnecessary to harden and grind the surfaces in contact as the elasticity of the rollers ensures that the load shall be distributed uniformly.

They are formed of steel strip, of section proportioned to the load to be carried, coiled on a mandrel into a close helix. Usually a roller with a right-handed helix alternates with a left-handed one; it is stated that there is no end thrust.

In one case the rollers are retained in a whole cage, the ends of which are bossed inward to keep the rollers in position without constraint. This is for a shaft 1·31 in. diam. and has eight rollers 0·62 in. diam. made of strip 0·31 in. wide by 0·12 in. thick.

The other example is a split bearing. The rollers are in loose contact with the shaft and with a steel liner split on a plane inclined to that of the diameter and contained within a swivelling sleeve with oil catchers at the ends. This is for a shaft 1·56 in. diam. and has eleven rollers 0·5 in. diam. made of strip 0·31 in. wide by 0·06 in. thick. M.4208–9.

1017. Roller bearings. Lent by the Empire Roller Bearings Co., 1898.

To keep the rollers parallel with the shaft, so that they shall have a distributed pressure, and also not jam themselves through travelling endwise, they are carried loosely in a cage which runs freely on the shaft and in the axle box, and has merely a controlling influence on the rollers when they are free from the bearing pressure, as patented in 1898 by Mr. T. Cooper. Such roller bearings for shafts of 1, 1·5, 2, and 3 in. diam. are shown in detail, also complete axle boxes for a railway carriage and for a tramcar fitted with these rollers. It is found that the starting effort in vehicles so fitted is reduced, while the great diminution in lubrication found possible effects also an important economy. M.3038.

1018. Roller bearings. Lent by Mossberg Roller Bearings, Ltd.. 1901.

This method of construction was patented by Mr. F. Mossberg in 1895–8. For a cylindrical bearing an annular cage is bored longitudinally with holes of greater diameter than its thickness; the rollers are then inserted and held in place by an end cap, with projections fitting into the roller spaces and retained by a spring clip. For an end-thrust bearing, the holes and rollers are conical, and the rollers are retained in position by an outer steel ring. M.3187.

1019. Roller bearing. Made by Messrs. Kynoch, Ltd., 1901.

This bearing, which was patented in 1896–9 by Mr. E. Jones, possesses the same advantage as does the Hyatt roller bearing (*see* No. 1016) resulting from the construction of the rollers of a hollow form possessing considerable elasticity. In this case the rollers are made from V-shaped stampings which, when coiled, form both right- and left-handed helices, thus neutralising any tendency to travel and cause end thrust. The rollers are made of unequal length in order to break joint, and are threaded on rods forming a split cage by which they are retained within a bored sleeve carried in a plummer-block. The example is for a 2 in. diam. shaft, and the cage, or live ring, contains fourteen rollers 0·5 in. diam. made from steel 0·06 in. thick. A spare stamping is shown. M.3189.

1020. Taper roller bearing. Lent by the Electric and Ordnance Accessories, Co., Ltd., 1910.

This is a specimen of the adjustable roller bearing patented by Messrs. H. Timken and R. Heinzelman and others in 1898, 1907, and 1908. As with other roller bearings, it will carry a greater load than a ball bearing of the same size, owing to there being line contact, but the rollers are inclined so that the bearing is adjustable for wear and is also capable of sustaining end thrust.

The bearing has an internal steel cone fitting the shaft, and provided with a circumferential ridge at each end. The rollers are made of tempered nickel steel and are tapered so as to roll correctly in their inclined position; a groove is turned near the smaller end of each roller, and this engages with the ridge at the smaller end of the cone, while the large end of the roller fits against the other ridge. The rollers are held in position by a steel cage stamped in one piece, and the ridges on the cone simply guide them and prevent cross-winding, but do not take the thrust. The rollers are surrounded by a steel cup having an internal conical surface with a total angle of 23 deg., which enables the bearing to support a thrust equal to the radial load. For adjustment, the inner cone and rollers are drawn into the cup by a nut on the shaft.

The example shown has an internal diameter of 35 mm. (1·38 in.), and has 12 rollers. It will carry a load of 625 lb. at a speed not exceeding 500 rev. per min. M.3801.

1021. Ball journal bearings. Lent by the Hoffmann Manufacturing Co., Ltd., 1910.

It has been shown by the experiments of Prof. Stribeck and others on ball bearings that the balls should not touch one another; also that for a given load the stress is considerably reduced and the compression of the ball and of the race is less when the race is grooved than when it is plane; and in this connection that it is of the greatest practical importance that the grooves should be highly polished. The bearings shown embody these features.

The journal bearings are designed for radial loads only. They consist of two concentric hardened steel rings grooved and polished for a single row of balls running between them. The number of balls is a maximum, space only being left for a gunmetal cage made in halves, riveted together, to retain them; a notch is cut in the side of each ring for introducing the balls, as patented in 1903 by Mr. A. J. Boult. The ring must be rigidly fixed to the rotating part. In the usual case, that of a shaft in bearings, the inner ring should be a press fit on a parallel or tapered part of the shaft and clamped by a nut. Where the bearing is in the middle of a shaft a tapered split sleeve tightened by a nut held by a set screw, as shown, must be used.

The bearings shown, with their safe working loads at 1,000 r.p.m., are:— Light type, 1·5 in. diam., 730 lb.; medium type, 1·25 in. diam., 1,210 lb.; medium type, with sleeve, 1·75 in. diam., 1,990 lb. M.3798.

1022. Ball bearings. Presented by Messrs. Ludwig Loewe & Co., Ltd., 1907.

Three forms of grooved race journal bearings are shown:—

(*a*) This has a full row of balls, *i.e.*, all the space in the race is occupied by balls. They are assembled by dropping them past a notch in the outer ring; a set-screw prevents them falling out. The screw introduces a weak spot into the ball race, and as any two adjacent balls revolve in opposite directions at their point of contact, wear is set up. This type is, therefore, obsolete.

(*b*) In this, adjoining balls are separated by two discs with a helical spring between. A depression in the disc serves to centre it on the ball and to attach the spring, while a spring clip or casing serves to limit the compression, as patented in 1904 by the Deutsche Waffen- und Munitions-fabriken. It is a light type, 60 mm. diam., and has a tapered split sleeve with nut for a shaft 50 mm. diam. The balls are assembled by dropping them between the inner and outer rings when placed eccentrically to one another, using force for the last ball.

(*c*) This only differs from the preceding in that it has, instead of springs, a gunmetal cage with lugs bent to embrace the balls and that it is a heavy type for 50 mm. diam. M.3513.

1023. Ball thrust bearings. Lent by the Hoffmann Manufacturing Co., Ltd., 1910.

These are designed for axial loads only, and consist of two hardened steel washers with grooved and polished ball races. A single row of balls held in a gunmetal cage runs between them. One washer is made a driving fit on the shaft, while the other one is loose; in the case of the medium and heavy types it is coned so as to centre itself readily in the housing providing for it, which is secured in the footstep, etc.

The bearings with their safe loads at 1,000 r.p.m. are:—Light type, 2·25 in. diam., 750 lb.; medium type, 1·5 in. diam., 830 lb. in housing; heavy type, 1·125 in. diam., 850 lb. in housing.

For an alternating or intermittent end thrust, a double thrust washer is used; this consists of three hardened and grooved steel washers, the centre one being of greater diameter than the others. They are variously fixed, but in the form exhibited the centre washer would be clamped between shoulders in the housing, etc., while the two outer washers are mounted on the sleeve with a disc nut; this sleeve would be clamped by nuts against a shoulder on the shaft.

The light type, 1 in. diam., safe load 570 lb. at 1,000 rev. per min. is shown. M.3799–3800.

1024. Self-aligning ball bearings. Lent by the Skefko Ball-Bearing Co., Ltd., 1911 and 1914.

These are specimens of the ball bearing patented by Mr. S. G. Wingquist in 1907. In it there are two rows of balls held in a cage and running in grooves formed on the inner race, while the outer race is bored to a spherical shape, so that the shaft and balls can swivel in it; a kind of ball and socket joint is thus formed, which allows the shaft to deflect considerably without injury to the balls or races. The balls in the two rows are staggered so that the maximum number can be used in a bearing of normal width; three of them carry the bulk of the load, and the bearing is capable of withstanding a certain amount of axial thrust. The inner races have a radius slightly greater than that of the balls, and a line joining the two points of contact of a ball passes through the centre of the bearing. The inner and outer contact surfaces are approximately equal so that the wear on the races is equalized. The cage is a phosphor-bronze ring with notches drilled in its edges; the balls are lightly sprung into these so that to dismount the bearing it is only

necessary to swing round the inner race and balls, and remove two balls, one at each end of a diameter, when the whole central portion can be withdrawn. The bearings are made of the best Swedish crucible cast steel, hardened, tempered, ground, and polished.

The large specimen shown is of the medium type for a shaft 50 mm. (1·97 in.) diam. It has 26 balls 14 mm. (0·55 in.) diam., and will carry a steady load of 2,750 lb. at a speed of 1,200 rev. per min.

The smaller specimens illustrate further applications: Two ball bearings, one complete and one in half section, of medium type, for a shaft 1 in. diam. are shown; in these the cage is of pressed sheet steel. A small shaft, intentionally bent, to show that transmission is not thereby interfered with when mounted on two such bearings, is shown. The plummer-block, in section, shows the screwed split sleeve necessary for adapting a bearing to any position on a shaft; this is for a 1 in. diam. shaft. A single thrust bearing, in section, for a 1·25 in. diam. shaft, and double thrust bearings, one complete and one in section, for a 1 in. diam. shaft, are also shown.

M.3918 and Inv. 1914–359 to 362.

1025. Stages in the manufacture of ball bearings. Lent by United Motor Industries, Ltd., 1912.

The successive stages in the production of a journal and of a thrust ball bearing by the Deutsche Waffen- und Munitions-fabriken, Berlin, are shown.

To make a ball, a short piece is sheared off a round steel bar, upset by die forging into a ball, trimmed, rough ground, hardened, fine ground, and polished.

For a journal bearing, a disc is parted off a round steel bar and the inner ring is parted from the outer; both are turned, hardened, ground, and the races polished. The balls are then inserted, and are retained in position by a cage. The blank for the cage is stamped out of sheet iron, and the edges turned up. Blanks for the separator pieces are stamped out, the edges turned up and inserted in the cage ring, whose edges are then folded down on them. When in position the separator pieces are pressed down on the balls. This construction was patented by the firm in 1907.

For a thrust bearing, a disc is parted off a round steel bar and the hole stamped out while red hot. The piece is turned, grooved, hardened, ground, and the ball race polished. The other disc is similarly made, but has a spherical seating. Blanks for the cage are stamped out of sheet brass, and holes are punched for the balls. A cage is formed of two discs, with balls between, held by shouldered rivets. M.4124.

1026. Thrust bearing. Lent by Messrs. Broom and Wade, Ltd., 1913.

Efficient lubrication of rubbing surfaces depends upon the maintenance between them of a film of oil. In a journal bearing this is easy, because at a limiting speed, oil is dragged in at a point of no pressure on one side quicker than it can escape at the other. In a thrust or footstep bearing this is difficult because there is no such point, and the co-efficient of friction is consequently high.

In the bearing shown, which was patented in 1905 and 1907 by Mr. A. G. M. Michell, the bearing surface is divided into a number of segments, each rocking on a radial line about one third of its width from the trailing edge. When a certain speed is reached, oil is drawn in under the leading edge of the segment, causing it to tilt very slightly, and this ensures a film of oil between the rubbing surfaces. The limiting pressure may be as much as 500 lb. per sq. in., *i.e.*, about ten times as in much as an ordinary footstep bearing.

An adjacent diagram of the co-efficients of friction for various types of bearings at different speeds shows that the curve for this bearing approaches very closely to that of the ball thrust bearing.

The thrust washer shown is for a steam turbine shaft, 2 in. diam. There are eight gunmetal segments held by an internal ring and by an outside split ring springing into a binding ring. Sufficient play is left to allow of the tilting of the segments. The whole bears on a spherical thrust washer prevented from turning by a pin in a fixed thrust sleeve. Finally, there is an end adjustment of the shaft by check nuts. M. 4223.

Couplings.

1027. Universal joint. Contributed by R. Bodmer, Esq., 1857.

This universal joint, patented by Mr. J. G. Bodmer in 1841, for enabling one shaft to drive another which is inclined to it instead of being in the same straight line, has a hollow boss on one shaft partly spherical; into this fits the end of the other shaft, which has a spherical boss. Two loose segmental blocks with pins are let into grooves in the solid spherical boss. The pins take into holes in the hollow boss, thus communicating motion. Inv. 1857–22.

1028. Muff couplings. Lent by the Kirkstall Forge Co., 1890.

This frictional shaft coupling, patented in 1879 by Mr. H. M. Butler. consists of a muff bored out conical at the ends to suit two tapered split bushes. The muff is placed, by aid of a sight hole, over the ends of the two shafts—which may differ in diameter—and the bushes are driven in by a special tool so as to grip the shafts by friction. Snugs ensure the splits being diametrically opposite so that the bushes can be driven out when necessary by the use of a narrow tool passing the split. In the larger sizes internal nuts at each end of the muff retain the bushes. The examples are for shafts 1·25 in. and 2 in. diam. The spanner and tools used are shown; a sectional drawing of the coupling is adjacent.

The shafting, on which three couplings are shown, is known as "rolled." It is finished at a dull red heat in a mill which consists essentially of two discs parallel to and facing one another but with their axes not in the same straight line. The discs rotate in the same direction and "planish" the shaft placed between them. If its centre is placed above or below the plane of the discs, it will travel longitudinally and issue sufficiently straight and cylindrical for nearly all purposes. M.2328.

1029. Flexible coupling for shafting. Lent by P. Brotherhood, Esq., 1890.

This flange coupling, patented in 1883 by Mr. Brotherhood, is designed for connecting two shafts so as to allow of a small error in their alignment as well as to permit a limited amount of end play and to obtain some elasticity in the driving connection. An annular disc of leather or other material is clamped at its outer circumference by a ring to the flange keyed to one shaft and similarly secured at its inner circumference to the flange keyed to the other shaft, as shown in an adjacent sectional drawing. A leather disc is exhibited which was in use for 12 months transmitting about 40 h.p. at 80 rev. per min. M.2288.

1030. Flexible shaft coupling. Lent by Messrs. Frank Wigglesworth & Co., Ltd., 1908.

This flange coupling is designed to give some flexibility at the point of connection, *e.g.*, when there is a slight error in the alignment of the shafts. The arrangement will transmit power in both directions; it can be used when one shaft is to be insulated from the other as in electrical driving.

An endless leather belt is interlaced between segmental shaped studs, half of them projecting from an annular ring bolted to one flange of the coupling and the other half projecting from the other flange; a disc bolted to the latter prevents axial displacement of the belt. Such couplings were introduced in 1894 by Mr. Louis Zodel and appear to have been developed from Raffard's coupling of 1885 (*see* drawing attached) in which separate elastic bands are used for each corresponding pair of studs projecting from the flanges. The example shown is for a shaft 1·75 in. diam.; the outside diam. is 12 in. and single belting 1·5 in. wide is used. M.3540.

1031. "Pillow" shaft coupling. Lent by Messrs. C. E. Lugard & Co., 1912.

In this form of flexible shaft coupling, the flange on one shaft is provided at the circumference with a number of shallow depressions to accommodate slotted tubes or "pillows" of different materials, in contact with similar recesses in an embracing flange on the other shaft.

The pillows are retained in position by a ring held by screws. If one shaft is to be insulated from the other, the pillows are of wired rubber or leather, but if not, of spring steel; both kinds are shown. The steel pillows in the larger sizes have their slots at an angle to the axis. The coupling shown is No. 1 size, which can be bored for a shaft 1·56 in. to 2·37 in. diam. M.4142.

1032. Model of reversing gearing and friction clutches. (Scale 1 : 6.) Contributed by R. Bodmer, Esq., 1857.

This arrangement was patented in 1843 by Mr. J. G. Bodmer, as a means for winding from mines with a non-reversible motor.

Two bevel wheels mounted loosely upon the motor shaft have pinions gearing with large spur wheels fixed to each of the winding drums. A third bevel wheel gearing with the first two runs loose upon a fixed shaft, so that the winding drums rotate in opposite directions. On a sleeve on the main shaft are two friction clutches, which may engage with either of the bevel wheels, while when in the intermediate position a brake acting upon the third bevel wheel is brought into action by a weight, and locks the wheel, thus stopping the winding drums.

The friction clutches employed were patented by Mr. Bodmer in 1839, and they embody the principle of the toggle joint. Each consists of three radial arms hinged to a sleeve and carrying segments which are forced against the internal rim of its bevel wheel. Inv. 1857-24.

1033. Model of Napier's differential clutch. (Scale 1 : 4.) Lent by Messrs. Napier Bros., 1899.

This friction clutch was patented in 1867 by Mr. R. B. Napier, as an improvement upon a brake patented in 1861 by Mr. R. Napier.

As shown in the model, there is a continuously rotated shaft upon which is secured a brake sheave, while loose on the shaft is a rope drum and a sliding collar by which the clutch can be closed or released. On the sheave is a brake strap, the two ends of which are connected with a bellcrank lever turning on a pin secured to the rope drum. The bellcrank arms are unequal, so that movement of this lever in one direction tightens the strap, and in the other direction lengthens it to an extent determined by the difference in length of the two arms. This movement of the bellcrank is controlled by two horns projecting from the sliding sleeve; these horns engage with inclined pieces, one fitted to the strap and the other to the rope drum, so that sliding the sleeve causes a relative motion of these two parts.

When the strap is tightened, any slipping action in one direction tends to increase the grip, while motion in the opposite direction releases it, so that

this arrangement is only suited for driving in one direction. In a modification patented in 1886 by Messrs. D. D. & W. D. Napier, two fulcra are provided for the bellcrank, and in this way double action is obtained. M.3055.

1034. Model of a hydraulic friction clutch. (Scale 1 : 8.) Lent by the Monkbridge Iron and Steel Co., Ltd., 1887.

This hydraulic friction clutch was patented in 1868 by Mr. F. W. Kitson and P. Chalas; the model shows its adaptation for reversing a rolling mill, as used at Monkbridge Works.

The crankshaft has two spur wheels keyed to it gearing with loose wheels on a countershaft, one train of which has an intermediate wheel so as to give a reversed motion. In the space on the countershaft between these loose spur wheels is keyed a casting, each face of which serves as a cylinder for a short annular hydraulic plunger on the back of a disc which is thus forced into contact with the loose wheel facing it. The two pipes for supplying the pressure water pass from the cylinders through a concentric hole in the shaft to a spigot which rotates in a stuffing-box, with the shaft. The spigot has two inlets arranged annularly, so that water can be supplied to either through pipes controlled by a valve. M.1868.

1035. Model of a friction clutch. (Scale 1 : 4.) Lent by Messrs. J. Bagshaw & Sons, 1888.

This is a form of friction clutch, patented by Mr. W. Bagshaw in 1884, for driving a single wheel or pulley. Within the large hollow boss of the wheel is a split ring of somewhat smaller diameter, which, in its normal condition, is capable of revolving within the boss without touching it. The action of a wedge and a pair of multiplying levers between the free ends of the split ring causes the latter to expand and press against the internal circumference of the boss of the wheel. The split ring is fixed at the centre of its length to the shaft, and the wedge is forced in by a hand lever. M.1880.

1036. Elastic clutch. Made by Messrs. Cowlishaw, Walker & Co., 1908.

This small clutch is of the construction patented in 1887 by Mr. R. Snyers; it is somewhat extensively used on the Continent where it is known as the Hoppenstedt clutch.

It consists of a flange keyed to the shaft and having screwed to its face a renewable annulus with radial metal fins projecting from it. On a feather in the shaft slides the other flange of the clutch having on its face a corresponding annulus in which are fixed brushes of flat steel wire. When closed together, the brushes slip over the metal fins without shock till the load has been picked up when the large number of flexible drivers represented by the brush wires is sufficient to give a reliable and elastic transmission.

The engaging or closing gear, patented in 1892 by Messrs. W. G. Cowlishaw and C. E. Walker, consists of a sleeve loose on the boss of the brush flange. Through this sleeve are two helical slots within which are rollers attached to a double-ended lever that is free between collars on the shaft but is held by two struts from the ceiling or from the floor. From the sleeve a handle projects horizontally but if at the ceiling two arms and a chain to each would be provided. This partial rotation causes axial movement of the sleeve but does not allow it to slack back. The shaft is 1·5 in. diam. The diameter of the brush surface is 13 in. outside and 7 in. inside. M.3566.

1037. Friction clutch. Lent by Messrs. Durham, Churchill & Co., 1907.

This type of friction clutch was patented in 1892 by Messrs. J. R. Churchill and F. G. Seeley.

On the continuously rotated shaft is keyed a sleeve terminating in a flange containing bosses for the driving pins. These pins act as carriers for the inner cone. The other end of the sleeve is recessed to contain a collar which provides the fulcrum for the operating lever. The lever is connected with a sliding collar on the sleeve by a strap and a pair of side links. Coupled to bosses on the flange of the sleeve are links passing through slots in the inner cone, and connected with the sliding collar by external links. Spiral springs contained between the flanges of the sleeve and the inner cone keep the conical surfaces in close contact when driving, and also follow up any wear which may take place on the frictional surfaces. When driving, the power is transmitted from the sleeve through the pins to the inner cone, and thence through the frictional surfaces of the two cones to a boss carrying the loose pulley, the flange of the boss being bolted to the outer cone. When the clutch is out of gear, rollers, carried on the pins connecting the links of the operating gear, bear on the face of the inner cone pressing it out of contact with the outer cone. M.3500.

1038. Coil friction clutch. Lent by the Consolidated Engineering Co., 1902.

In this clutch, which was patented in 1893–5 by Mr. W. H. Lindsay, the closing pressure is derived from the grip of a coil which passes several times round a smooth drum and has its slack end controlled by the brake lever.

To the continuously running shaft is keyed a small drum, embraced by a helical spring of square section and of 4·5 turns, which is bored out to clear the drum freely. One end of the spring is secured to an enclosing casing to which the pulley to be driven is keyed, while the other end is attached to a lever on the end cover of the casing. Through this cover an ordinary clutch sleeve passes, the end of which is made conical, so that when forced inward it moves the lever and causes the spring to tighten on the drum. The cover of the case is secured by screws and slotted holes, by which means the clearance between the coil and drum can be adjusted.

This clutch will only drive in one direction, but can be converted for driving in the opposite direction by the substitution of a spring to reverse hand. M.3217.

1039. Benn friction clutch. Presented by the Unbreakable Pulley and Millgearing Co., Ltd., 1912.

This is an example of the form of friction clutch patented by Mr. H. H. Benn in 1899 and 1901.

It consists of a closed cast iron drum, keyed to one of the shafts, and having within it a pair of cast iron friction rings carried loosely on pins which are fixed to lugs on a boss keyed to the end of the adjacent shaft. The rings are free to move endwise, and are thrust apart and into contact with the sides of the drum by toggles which are actuated by levers pivoted on a sliding sleeve and having their outer ends tied together by yokes and springs. The movement of the sleeve by the striking gear only puts the friction rings into contact with the drum faces, the driving pressure being obtained from the springs through the levers and toggles, which are then in their most advantageous position. The links connecting the toggles with the levers pass beyond their mid position when the clutch is fully engaged, thus causing it to be locked there. Adjustment of the clutch faces is provided for by making the face of the drum through which the sliding sleeve passes separate, and screwing it into the casing, where it is secured by a set screw that engages with one of a series of slots cut on its edge. The clutch has its working parts entirely enclosed, the casing being used as an oil-bath. The driving thrust is self-contained and the striking gear is free from it. The clutch may be used for coupling two shafts, or to connect a pulley with a shaft, the drum being then bolted to the boss of the pulley.

The example shown is suitable for shafts from 3·375 in. to 4·75 in. diam., and will transmit 16 h.p. at 100 r.p.m. under ordinary conditions. It is, however, shown mounted on shafts 2 in. diam. with adapter sleeves in the clutch. The shafts are supported by two adjustable swivelling cast iron bearings, fitted with ring oilers. These clutches are made in various sizes to transmit from 5 h.p. to 1,600 h.p. M.4051.

1040. Friction coupling clutch. Lent by the British Hele-Shaw Patent Clutch Co., Ltd., 1907.

This is a small example of the form of clutch patented by Dr. H. S. Hele-Shaw in 1901–2. It is an improved form of the Weston multiple plate clutch, in which the flat plates are replaced by a number of thin plates, each stamped with an annular V-shaped corrugation; the plates fit into one another and are pressed together by springs. This arrangement gives increased gripping power, while the spaces left between the plates, and at the bottom of the corrugations, allow them to be lubricated so as to reduce the wear when slipping, and give a large surface for radiating the heat generated.

The plates are placed in a cylindrical casing which is keyed to one shaft, and one set of the plates, which are of copper, have notches round their outer edges engaging with pins fixed in the casing. The other shaft passes through a bearing in the casing and its end is keyed to a sleeve having feathers which engage with notches formed on the inner edge of another set of plates; these are of steel and alternate with those of the first set. The clutch is brought into action by a sliding sleeve and forked lever; pins attached to the sleeve pass through the casing and press upon the plates at one end, forcing them together and against another set of spring-supported pins at the other end; bearing rings are interposed between the pins and clutch plates. Triggers are fitted to the sleeve which holds the clutch in gear when fully engaged, but which are released by the backward movement of the forked lever that takes place before the sleeve can be moved. There are nine plates in this specimen having a mean diameter of 3·75 in. for a shaft 1 in. diam. M.3516.

1041. Expanding clutch. Lent by Capt. Théo. Masui, 1910.

This is a specimen of the metal-to-metal expanding clutch used on the "Germain" motor cars to connect the motor shaft with the gear box.

The motor flywheel has bolted to it a steel drum, the inner surface of which is drilled with shallow holes to retain the lubricant. The inner member of the clutch is a single expanding ring, one end of which is adjustably pinned to an arm on the shaft, while the other end has a cylindrical hole through it within which fits an eccentric pin also mounted on the arm. One end of this eccentric is fixed to a lever, a roller on which is held by a spring in contact with a cone that can be moved endwise on the shaft by the usual pedal, so that when the cone is moved forward the lever moves outward, thus rotating the eccentric and expanding the clutch ring. The expanding mechanism is balanced by a counterweight, and the ring is held central by three stops; the whole is enclosed by an aluminium cover. M.3809.

Spur Gearing.

1042. Gearing for variable speeds. Contributed by R. Bodmer, Esq., 1857.

This is an arrangement of gearing, patented by Mr. J. G. Bodmer in 1841, for driving lathes and other machinery at varying speeds through the medium of nest gearing. On the end of the shaft of the machine to be driven is mounted a pair of radial arms, carrying a pair of intermediate pinions, the teeth of which gear into a central pinion and also into a concentric internal toothed wheel, the latter being mounted on a hollow shaft through which passes the shaft carrying the central pinion. By means of

cone pulleys the relative speeds of the central pinion and of the internal wheel can be varied, thus varying the rate at which the intermediate pinions are carried round and, consequently, the rate at which the machine is driven.

Inv. 1857–23.

1043. Humpage's reduction gearing. Received 1899.

This mechanism, patented in 1887 and 1892 by Messrs. Humpage & Jacques, is an epicyclic train of bevel wheels by which two shafts on a common axis are so connected that they run at very different speeds. Though primarily designed as a substitute for the back gearing of lathes, it has been successfully used to transmit power from a high speed electric motor to slow-running machinery. In addition to the reduction that it accomplishes, it enables the machinery to be stopped or started without interfering with the running of the motor; the mechanism can also be used as a differential gear.

In the arrangement shown a pinion of 12 teeth, secured to the end of the driving shaft, engages with a wheel of 40 teeth, which is carried on an arm turning loosely round the axis of the shaft. Secured to and co-axial with this wheel is a wheel of 19 teeth, which engages with another of 36 teeth, secured to the driven shaft. The wheel of 40 teeth also engages with one of 48 teeth, which forms the end of an oil-tight drum-shaped gear-case, which encloses the mechanism, and, though normally stationary, is held in a clamp by which it can be readily released. When this wheel is loose no power is transmitted, but if it be held the driven shaft will make one revolution for every 13·64 made by the driver. If the wheel or its drum be independently driven a differential motion is obtained, whereby the speed of the driven shaft may be increased, diminished, or reversed.

The movement of the drum is particularly useful in the case of an alternating motor, which will not start against a load, for on releasing the drum the motor has only to turn it backward in its bearings, and when the motor has got up speed the load can be picked up gradually. To balance the pressures the arm and its wheels are all duplicated. M.3048.

1044. Ross's speed-reducing gear. Lent by Messrs. R. G. Ross & Son, 1902.

This compact form of epicyclic gearing was patented by Mr. J. M. Ross in 1896, and is used for coupling high speed motors to machine tools, winches, etc., requiring to run at a much lower speed.

The gear is enclosed in a casing made in two parts bolted together, each of which carries a short shaft in a long gunmetal bearing, the two shafts being in line. On the end of the driving shaft is a crankpin carrying a double toothed wheel, the larger portion of which has 33 teeth and gears with a stationary internally-toothed ring having 39 teeth, while the smaller portion has 22 teeth and gears with an internally-toothed wheel having 26 teeth which is attached to the driven shaft. When the motor shaft revolves, the crankpin carries round the double toothed-wheel, which is thereby caused to rotate on its axis in the opposite direction by the fixed toothed ring; the combination of these rotations causes the driven shaft to revolve in the same direction as the motor shaft at a reduced speed, the reduction in this example being 14 : 1.

The crankpit and wheels are counterbalanced and the casing is utilised as an oil bath. M.3228.

1045. Differential gear for motor cars. Presented by O. S. Thompson, Esq., 1906.

The application of the bevel or spur wheel differential gear to self-propelled road vehicles, as a means to enable either of a pair of driving wheels to overrun the other when moving in a curved path, was patented in 1832 by Richard Roberts. The example shown is a spur wheel gear used on an 18 h.p. "Siddeley" motor car.

The car is chain driven, and the differential gear is fitted inside the change-speed gear box, on an axle which carried the chain sprocket wheels at its outer ends. This axle is divided near the middle and each portion has at its inner end a spur wheel formed in one with it. Surrounding these wheels is a box made in halves, bolted together, and carrying four fixed spindles upon which are freely mounted two pairs of wide-faced spur pinions. Of each pair of pinions, one gears with each of the wheels on the divided shaft, while they also overlap and gear with one another for one-half their lengths. The pinion box itself revolves on ball bearings and has bolted to it a bevel wheel which is driven by a similar wheel on the longitudinal change-speed shaft. When the car moves in a straight line the spur wheels and box revolve as a whole, but should one road wheel be retarded as when turning, the pinions rotate on their spindles and allow the other road wheel to revolve more rapidly. K.596.

1046. Motor car change speed gear. Presented by the Albany Manufacturing Co., Ltd., 1906.

This is an example of the change-speed gear designed by Mr. F. Lamplough for use on a 10 h.p. motor car. The car has a single cylinder horizontal motor with a transverse crankshaft, and the power is transmitted to the change-speed gear, whose axis is placed longitudinally, through a cone clutch and worm gearing, and from thence by a propeller shaft to a live rear axle. The drive is direct on the high speed, but a lower speed and a reverse are provided by epicyclic gearing.

The gear box is in halves, the upper part carrying the driving worm and a separate casting enclosing it. The box contains a through shaft supported in bearings at each end, and upon the middle of this is loosely mounted the worm wheel, which has a boss of considerable length. The speed-changing gear consists of an epicyclic train, the central wheel of which is keyed to the front end of the worm wheel boss, while the internally toothed outer member runs loose and has an external flange provided with notches. The intermediate pinions are mounted on pivots fixed in the flange of a sleeve which is keyed to the shaft. Upon this sleeve is keyed by feathers a sliding collar having three projecting clutch pins which pass through the pinion flange and enter bushed holes in the outer member of the gear, so locking the worm-wheel to the shaft and producing the direct drive. On the other side of the worm-wheel is a similar train of wheels for reversing, but in this case the outer member is fixed to the shaft, while the pinion carrying sleeve is loose; it has also a notched flange and an extra bearing surrounding it. The sliding collar is embraced by forks which are fitted to arms on a transverse shaft in the bottom of the gear box and moved by a hand lever. The forks are also connected with a pair of sliding bars fitted in grooves formed between the two parts of the gear box; these bars have projecting teeth which are so arranged as to engage alternatively with the notches in the flange of the rear wheel train, giving the reverse at half-speed, or with those of the outer member of the forward train, giving the low speed which is one-third the high. When neither clutch pins or bars are engaged, the worm-wheel runs free.

The worm shaft bearing on the side next the motor is lengthened and has cut on it a quadruple screw thread; a lever fitted to this actuates the driving clutch, and its position is adjusted by rotating the bearing by means of spur gearing and an external key spindle. Ball thrust washers are provided on the worm and gear shafts. The rear end of the gear shaft carries a brake drum and finishes in a forked end for a universal joint. M.3435.

1047. Motor car change speed gear. Presented by Messrs. E. G. Wrigley & Co., Ltd., 1911.

This is a gear-box of the gate type suitable for a motor car of 20–30 h.p. It gives a direct drive on the high speed, three forward speeds and a reverse.

The advantage of the gate gear over the old form of sliding wheel gear is that any one gear change can be made without passing through any other.

The main and the countershaft are mounted side by side in the gear-box and both run in ball bearings. The main shaft is in two parts, the rear portion being a short shaft having an internally and externally toothed wheel at its inner end, while the outer end is attached to the longitudinal shaft that drives the rear axle. The forward part of the shaft is supported inside the rear piece, has four key-ways along it, and carries two separate sliding spur wheels with collars for moving them. The countershaft carries three fixed spur wheels of different sizes, the smallest one, at the rear end, being always in mesh with the external teeth of the fixed spur wheel on the main shaft. One of the sliding wheels, when in its rearward position, engages with the internal teeth of the adjacent wheel and so gives a direct drive on the highest speed; in its forward position this wheel engages with the second spur wheel on the countershaft, giving to the propeller shaft a speed 55 per cent. of the high. The other sliding wheel, in its rearward position, engages with the third countershaft wheel and gives a speed 35 per cent. of the high; in its forward position it engages with a wheel on a second short countershaft, and simultaneously brings a second pinion on the latter into gear with the third wheel on the countershaft, thus giving the reverse motion.

The actuating gear consists of a hand lever the normal position of which is in the gate between two slots formed in a quadrant; in this position of the lever the engine is free from the gears. The two sliding wheels are moved by sliding forks, operated by separate levers, one fixed to the hand lever shaft, and the other to a sleeve which is loose upon it. These levers have each a spring arm extending upwards, one on either side of the hand lever which is loose upon the shaft; when the hand lever is moved sideways out of the gate it engages with one or other of the spring arms and so operates the gears.

M.3842.

1048. Live axle and worm gear for motor cars. Lent by the Lanchester Motor Co., Ltd., 1907.

This is a sectional example of the live axle, differential, and worm driving gear used on the Lanchester motor cars. One half of the axle with its fixed outer casing is shown, and a short portion of the other half with the complete differential and worm gears.

The live axle runs on roller bearings and its two halves are connected by a differential gear of the bevel-wheel type, whose outer member carries a phosphor-bronze worm-wheel driven by a steel worm coupled to the longitudinal motor shaft. The worm-shaft runs on roller bearings and is fitted with a ball thrust bearing of the type patented by Mr. F. W. Lanchester in 1901, in which the balls run at different radii between two flat collars. The axle casing is provided with attachments for the springs and trussing rod. M.3521.

1049. Variable speed gear. Lent by George Thomas, Esq., 1913.

This experimental variable speed gear, applicable to motor cars, was patented in 1906 by Mr. Thomas. The drive takes place through an epicyclic train, one of the elements of which is driven at a variable speed by disc and roller friction gear.

The epicyclic train consists of a sun wheel on the driven shaft and an equal planet wheel bearing in a box on the end of the driving shaft. The planet wheel is in one with a worm-wheel, into which gears a double threaded worm on whose axis is a friction disc driven by a roller sliding on a sleeve on the driving shaft. In one extreme position the sleeve is free, so that the whole runs solid, *i.e.*, both shafts run at the same speed in the same direction. In other positions the sleeve is locked to the driving shaft by a band brake, and a ratio of speeds up to about 1 : 8, according to the position of the roller on the disc, can be obtained. The thrust of the worm is arranged so that it will bring the disc into contact with the roller. Inv. 1913–133.

Belt Gearing.

1050. Screw boss pulleys. Lent by Messrs. Smith and Grace, 1890.

These show a device, patented in 1885 by Messrs. G. E. and N. Smith, for fixing pulleys to shafting without keying. The eye of the pulley is bored and screwed conically, and fitted with a similarly screwed bush. This bush is split into three or four sections which are flexibly jointed by being cemented to a piece of emery cloth. To fix the pulley, the bush is placed on the shafting and the pulley screwed on to it till the shafting is so powerfully gripped that no keying is necessary. The pulley should be so placed on the shaft that the action of the belt tends further to tighten the bush. Spare bushes enable the same pulley to be used on shafts of different diameters. M.2332.

1051. Wooden pulley. Presented by the Flender Company, 1912.

The advantages of wood over iron as a material for pulleys for the transmission of equal power are: greater lightness, better frictional grip for the belt, and easier attachment to the shaft.

In the pulley shown, tendency to warp out of round is obviated by building up the rim of segmental pieces of white wood, dovetailed, glued and pinned together so as to break joint in the width. The pulley is split and the halves are toothed into one another at the rim, The two arms are of beech and are tenoned into the rim. The pulley is held on the shaft by the friction of a wooden bushing, tightened by four bolts in the arms.

The pulley is 24 in. diam. by 8 in. wide and is bushed for a shaft 2·5 in. diam. M.4167.

1052. Link belt drive. Presented by Messrs. Thomas Whittle and Sons, Ltd., 1913.

This form of belt consists of one steel and two leather links alternately. The steel link with its pins is a drop forging with its bearing parts machined. The leather links are held on the pins by a wood screw through their middle. They have a side taper for use on V-grooved pulleys having an angle of 28 deg. Considerable frictional adhesion is thus obtained while the flexibility gives good wrapping contact. The belt may be taken apart at any individual link and therefore no special fastener is required. Short links to make up for stretching, etc. are supplied.

The belt is employed at speeds between 500 and 3,000 ft. per min. It is made in sizes from 0·5 in. rising by eighths to 1·25. in. wide, transmitting at the higher speed from 1·5 to 15 h.p. if the diameter of the pulleys is not less than seven times the width of the belt. M.4263.

1053. Model of expanding belt pulley. (Scale 1 : 4.) Made from drawings supplied by the West End Engine Works Co., 1911.

This shows an arrangement for obtaining a variable velocity ratio between two shafts when employing belt gearing. The particular case for which it is used is that of a machine for cutting paper to certain lengths.

The circumference of the pulley is divided into segments, each of which is on an arm which can slide radially in V-guides on a disc keyed to the shaft. Each segment is actuated by links pinned to a sleeve sliding on a feather along the shaft and worked by the forked lever shown, or other convenient means. The pulley shown is for a maximum diameter of 24 in. with a range of 3 in. M.3834.

1054. Friction cone variable speed gear. Received 1913.

This variable speed transmission device was patented in 1887 by Mr. G. F. Evans.

It consists of two cone pulleys in frictional contact through the medium of an endless leather belt loosely encircling the upper or driving pulley. In order to grip the belt the bearings of the lower or driven pulley are adjustable vertically by screws, the levers on which are connected and are actuated by a hand wheel. Variable speed is obtained by shifting the belt along the pulleys by a fork slid along a square bar by means of a cord over a pulley at either end.

The example shown is a hanging pattern for a shaft 1 in. diam. and belt 2 in. wide. Assuming the driving shaft running at its normal speed of 300 rev. per min., the speed of the driven shaft may vary between 125 and 720 rev. per min., *i.e.*, a total ratio of 1 : 5·6. M.4258.

1055. Coiled steel bands. Contributed by the Perpetual Tension Propelling Belt Co., 1881.

These are samples of bands and cords made of coiled steel wire, intended for use in place of gut or round leather bands for driving light machinery. M.1525.

Rope Gearing.

1056. Fowler's clip pulley. (Scale 1 : 4.) Presented by Messrs. John Fowler & Co.

This shows a form of V-grooved pulley, first patented in 1859, in which the sides of the groove are formed of numerous hinged plates, which can be closed together to compensate for wear of the rope. These plates are carried upon bearings at the back, so situated that the downward pressure of the rope causes a swinging together of the plates, the leverage being such that the side pressure is much greater than that downward, so that the grip is thereby increased. Such pulleys are used for transmitting power by wire ropes, as owing to the increased grip obtained the wire rope exerts a greater driving effort than with a simple grooved pulley. M.2907.

1057. Driving arrangement for wire rope (working.). (Scale 1: 4.) Lent by F. W. Scott, Esq., 1896.

The power to be transmitted is given off by a double cylinder horizontal engine, which, by reducing gear and claw clutches, drives two four-grooved pulleys, which each carry an endless wire rope. In line with each pulley is a three-grooved pulley running loose in bearings, and the wire rope in each case returns three times over the loose pulley again on to the driving pulley, so as to obtain about four times the frictional grip that it would have if simply led on and off again as an open belt.

The model represents a plant for driving two endless ropes, for hauling to-and-fro along separate roads the small trucks used in mines.; in such cases the engines are frequently driven by compressed air supplied from the surface. At the end of each road is a return sheave, carried in an adjustable frame, by which the stretch of the rope may be taken up. For cable tramways a similar driving arrangement is adopted, but the slack is then usually adjusted by a powerful gear that slides the return pulley in the engine-room further away from the driving pulley. M.2948.

1058. Wire rope spears driving a mine pump. (Scale 1 : 12.) Made by T. B. Jordan, Esq., 1865.

In this arrangement the heavy wooden spears of shaft pumps are replaced by a wire rope. This is carried over large guide pulleys placed at the top

and bottom of the shaft and connected by short projecting arms with the pump plungers, which are reciprocated alternately. The top pulley may be oscillated by the usual connecting rod of the ordinary bellcranks, or may be replaced by them. The plan has been adopted in the Harz and in Sweden. M.1412.

1059. Bowden wire mechanism. Lent by the E. M. Bowden's Patents Syndicate, Ltd., 1907.

This is an example illustrating a mechanism patented by Mr. E. M. Bowden in 1893, the special use of which is to transmit power from one point to another in any direction, where a straight course between the points is not available, without the intervention of angle levers and joints. The mechanism consists of an incompressible flexible tube containing loosely within it an inextensible flexible wire. The outer tube has its ends securely anchored and it may take any course between them; one end of the inner wire is attached to a suitable lever while the other end is attached to the object to be moved, so that when the lever is actuated the wire slides relatively to the tube and transmits the power. A spring is employed to return the lever to its original position. The outer tube is usually formed of a closely coiled wire and the inner member of a stranded steel wire.

This mechanism first came into prominence for actuating cycle brakes and is of wide application. The specimen shown is arranged for adjusting the commutator of a petrol motor, the actuating lever being in this case locked in any position by the friction of a compressed spring washer. M.3522.

1060. Model of continuous rope drive. (Scale 1 : 8.) Made in the Museum, 1910.

The advantages of ropes over belts are that the speed of transmission is usually higher and that the grip is greater owing to the wedging action of the rope in the grooved rim. With ropes, too, the shafts need not be quite parallel and their distance apart may be much greater than with belting, so that the amount of bevel gear and shafting in a mill can be diminished.

The model shows a means whereby, instead of a separate rope for each groove, a single continuous rope may be used: a guide or cross-over pulley leads the rope back from the last groove of the driver to the first groove of the follower. By this arrangement less distance between the shafts is required than with separate ropes and only one splice is required while the disadvantage of short ropes is avoided. A single rope of n turns should transmit as much power as the sum of n separate ropes, but it is claimed that, in practice, the power transmitted is greater owing to the tensions being automatically regulated.

The arrangement shown was employed in 1883 by Mr. J. S. Raworth for coupling a steam engine and a dynamo where space was restricted. The larger pulley represents the grooved flywheel and the smaller one the dynamo pulley. To alter the tension, the position of the dynamo or else that of the guide pulley is adjustable.

Generally in rope transmission the lower side, instead of the upper as shown, is made the driving side as the arc of contact is thereby increased by the sag of the rope. M.3779.

1061. Model of crossed rope drive. Made in the Museum, 1910.

When it is wished to reverse the directions of rotation of two shafts a crossed rope may be employed just as is done with a belt. The great objection to this practice is the rubbing of the rope against itself and consequent wear. The wear of a rope on its neighbour may be diminished by putting them on the pulleys alternately right and left, so that contiguous ropes travel in the same direction.

The model shows a somewhat similar method, applicable, however, only to pulleys with multiples of two or three grooves, of minimising also the wear of the rope upon itself. The rope is made long enough to embrace two grooves and is wrapped round as shown so that adjacent parts of the rope travel in the same direction. Greater clearance where the rope crosses may be obtained by missing a groove, *i.e.*, occupying three grooves instead of two for each rope as shown. The sides of the groove are inclined at 45 deg., but the pitch of the grooves is greater and the depth is less than in the case of pulleys designed for straight driving with open ropes. M.3780.

1062. Model of endless rope drive. (Scale 1 : 8.) Made in the Museum, 1910.

This arrangement for endless rope driving with loose guide pulleys was introduced in 1889 by Mr. J. Barbour to meet similar cases to that in No. 1060, where two shafts are too close together to admit of separate ropes for each groove or where there is no room for a tension pulley.

The rope is wrapped round the pulleys and, instead of a cross-over pulley for the purpose of bringing it back to the starting point, an additional single grooved pulley is mounted loose on the shaft next the last groove of the driver and a similar one next the first groove of the follower. These pulleys are sufficiently larger in diameter than the fixed pulleys beside them to allow the rope to pass clear across itself working in the fixed pulleys. The angle of the groove is 45 deg., but the pitch is greater and the grooves are shallower than when separate ropes are used. A number of these drives have been installed, and have proved successful. M.3819.

1063. Model of continuous rope drive. (Scale 1 : 12.) Made by Messrs. T. J. Marshall & Co., Ltd., 1910.

This shows a method of transmitting power by a continuous rope to a number of different points and of obtaining there a variable velocity ratio. The mechanism was patented in 1896 by Mr. J. White and was designed particularly for high-speed paper-making machinery to take the place of the older spur gearing; the rate of shrinkage of paper as it is passing through the drying rolls not being invariable for all qualities, it is found desirable to be able to adjust the speed of the rolls individually; this is not practicable with spur gearing.

The rope pulleys, one of which might be the driver, are supported on pillars in a frame. The rope is laced round them in turn and the slack is taken up by a "stent" or tension pulley sliding on the frame. From each rope pulley the power is transmitted to the drying-roll shaft by the intervention of cone pulleys, belting and spur gearing. The spur pinion and one cone pulley are on bearings on a frame which has its fulcrum on the roll shaft. This frame can be raised or lowered within limits by a lever to tighten or slacken the belt when starting or stopping the rolls. M.3784.

1064. Model of expanding rope pulley. (Scale 1 : 4.) Made from drawings supplied by Messrs. Charles Walmsley & Co., Ltd., 1911.

This shows an arrangement for obtaining a variable velocity ratio between two shafts when employing rope gearing. The form of pulley shown was patented in 1856 and 1859 by Mr. J. Combe, but in this particular case, which is that of a machine for cutting paper to certain lengths, the details have been arranged by the makers.

The pulley is in halves, facing one another so as to include a total angle of 45 deg. One half is keyed to the shaft, the other is adjustable axially along a feather by a square-threaded screw and hand-wheel fixed on the end of the

shaft; the conical portions of the pulleys are slotted so that the solid parts of one half will mesh with the slots of the other.

The pulley shown is for a maximum diameter of 40 in. with a range of 20 in. M.3849.

Chain Gearing.

1065. Block driving chains. Presented by Messrs. Hans Renold, Ltd., 1911.

This form of chain is much used for driving low-speed machinery, and for conveyors, elevators, etc., where the solid block links are well adapted for securing various attachments. They are suitable for transmitting from 0·25 to 100 h.p. at chain speeds from 200 to 500 ft. per min.

The chain is made up of alternate pairs of steel plate links and solid blocks, the plate links being fastened together by hardened steel shouldered rivets which pass through holes in the ends of the blocks. The driving sprockets are made with a pitch slightly greater than that of the chain, so as to allow the latter to engage correctly, even when the pitch is increased by wear.

The chains are made in two series with short or long blocks, and the pitches vary from 0·75 in. to 6 in. The following three specimens are shown:—Short block series: 0·75 in. pitch, 0·18 in. wide, breaking load 1,130 lb., weight 0·125 lb. per foot; 3 in. pitch, 1·6 in. wide, breaking load 21,600 lb., weight 5·41 lb. per foot. Long block series: 3·75 in. pitch, 1 in. wide, breaking load 8,300 lb., weight 1·75 lb. per foot. M.3971–3.

1066. Bush roller driving chains. Presented by Messrs. Hans Renold, Ltd., 1911.

The roller pitch chain was invented by Mr. J. Slater in 1864, but the improved bush form shown was patented by Mr. H. Renold in 1880, 1891, and 1899.

The chain is built up of pairs of inside and outside steel plate links connected together, the inside links by steel bushes upon which the rollers run, and the outside links by shouldered steel rivets passing through the bushes. The bushes, rollers and rivets are turned from steel bar. The rivets and bushes are case-hardened, ground to size, and are force fits in the holes in the links; the ends of the rivets are softened and countersunk, so that they can be slightly riveted over afterwards. The bushes distribute the load over the whole length of the rivet, and thus reduce the wear and consequent increase in pitch. The chain joints are usually made with a bolt and nut.

In order that the chain may engage correctly with the teeth of the sprocket wheels, even when the pitch has been increased by wear, the teeth of the driving wheels are made with a slightly greater pitch than the chain, and considerable clearance is provided for the rollers; the driven wheels require the roller clearance only. The chains are made in four standard classes with pitches from 0·5 in. to 5 in. They are suitable for powers of 0·25 to 200 h.p., with chain speeds from 400 to 900 ft. per minute. The factor of safety employed in their design varies from 10 to 45, and depends upon the speed and pitch of the chain and the number of teeth on the sprockets. The following four specimens of the standard short pitch chain are shown:—0·5 in. pitch, 0·125 in. wide, minimum breaking load 1,850 lb., weight 0·19 lb. per ft.; 1·75 in. pitch, 1 in. wide, breaking load 21,500 lb., weight 4·2 lb. per ft.; 2·5 in. pitch, 1·5 in. wide, breaking load 57,000 lb., weight 10·4 lb. per ft.; 3 in. pitch, 1·8 in. wide, breaking load 86,000 lb., weight 17·75 lb. per ft. M. 3976–8.

1067. Morse pitch chain. Lent by the Westinghouse Brake Co., Ltd., 1908.

This is a specimen of the rocker-joint chain, patented by Mr. E. F. Morse, in 1893 and subsequently improved.

The chain is of the toothed type, and is built up of a number of flat links placed side by side, and having one end of each formed as a projecting tooth which engages with teeth cut in the rims of the driving and driven wheels. The joints of these links, instead of being made with cylindrical pins passing through them, consist of two joint pieces of hard steel, one of which, called the seat pin, has a plane face, while the other piece, called the rocker pin, has a curved face and rolls upon the seat pin as the joint passes on to or off the wheels; in this way the sliding action and its consequent wear are avoided. In order to prevent vibration at high speeds, the rocker pins are so shaped that they present broad bearing surfaces to the seat pins when the chain is straight. A seat pin is fixed in the smaller end of each link, and a rocker pin facing it in the opposite end, so that at each joint the alternate links have fixed connection with one joint piece, and the adjacent end of the intermediate links are connected with the other joint piece. The pressure upon the joint is distributed over the whole width of the chain, and the backs of the joint pieces are quite clear of the holes in the adjacent links through which they pass. The small ends of the outside links are off-set laterally, so that each link has the same area, and the reduced ends of the seat pins pass through them and are riveted over washers, which also prevent the rocker pins from moving endwise. In order to guide the chain, projecting links are inserted along its centre, and these enter grooves formed in the wheels. The driving faces of the pinion teeth are made approximately radial.

Chains of this kind are being used to transmit as much as 500 h.p.; the specimen shown has a pitch of 0·9 in., a width of 2 in., its working load is 380 lb., and it weighs 3·1 lb. per ft.; its running speed is up to 1,400 ft. per min. Some of the washers are partly cut away to show the action of the joint. M. 3546.

1068. Bush silent chains. Presented by Messrs. Hans Renold, Ltd., 1911.

The silent driving chain, patented by Mr. H. Renold in 1895 and 1900, lies on the face of a toothed wheel like a belt, and drives by means of projecting teeth that engage with the wheel teeth. The teeth of chain and wheel are straight sided, and any increase of the chain pitch due to wear is compensated by the chain riding up the wheel teeth until it gears on a correspondingly larger pitch circle. This construction causes the driving load to be distributed over all the chain and wheel teeth in gear, and the chain runs practically silently even at high speed; they can also be made of any strength without increasing the pitch. The chains are used for driving all kinds of machinery, either replacing belts, or in situations where belts or spur gearing could not be applied. They are made to transmit from 0·25 to 500 h.p., and run at speeds up to 1,300 ft. per min.

The first chains of this type consisted of thin plate links threaded on studs, but the narrow bearing surfaces and excessive wear at the joints led to the introduction of hardened steel bushes forced into the holes at the ends of the links. The link plates are now thicker, and are punched out of steel plate; their sides are ground flat, and the outer faces of their teeth which engage with the wheel teeth are accurately ground, so that they include an angle of 60 deg. The plates are bushed and threaded on to hardened steel studs, the number of plates varying according to the width of chain required. The studs have shouldered ends, on which washers are secured by riveting; they are free to turn in the links so as to equalise the wear.

The chains are guided on the wheels either by side flanges or by a central groove, with which guide plates fitted at the centre of the chain engage.

The bush silent chains are made in several sizes from 0·5 in. to 1 in. pitch, and up to 6·5 in. wide. The following specimens are shown:—21 tooth pinion 0·5 in. pitch, with chain 1·4 in. wide, minimum breaking load 4,750 lb., weight 1·28 lb. per ft., to transmit 2·04 h.p. Chain 1 in. pitch, 2·3 in. wide, breaking load 14,800 lb., weight 4·4 lb. per ft., to transmit 8·2 h.p. M. 3979–80.

1069. Liner silent chains. Presented by Messrs. Hans Renold, Ltd., 1911.

These chains are similar in principle to those adjacent, No. 1068, but the links are joined together in the manner patented by Mr. J. M. Dodge in 1904, and Mr. H. Renold in 1910. This is now the standard type of Renold silent chain for all pitches above one inch.

Instead of each link plate having its own cylindrical steel bush, two segmental hardened steel bushes embrace the studs, one on each side, and extend over their whole length. One of these bushes is fixed in the outer side of the holes in one set of link plates, while the other bush is fixed in the holes of the adjacent set. The load is thus distributed over the whole length of the studs, which are free to revolve so as to equalise the wear, and the lubricant easily finds its way between the bushes to the studs. The holes in the link plates are punched with notches to hold the bushes, and are made large enough to clear the opposite bushes and to permit the chain to bend.

The chains are made in several standard sizes from 1 in. to 1·75 in. pitch, and up to 12·2 in. wide. The following specimens are shown:—Length of chain, for a flanged wheel, 1·5 in. pitch, 2·9 in. wide, minimum breaking strength 20,400 lb., weight 8·55 lb. per ft., to transmit 28·2 h.p. Length of chain, for wheel with two guiding grooves, 1·75 in. pitch, 12·2 in. wide, breaking load 107,100 lb., weight 41 lb. per ft., to transmit 145 h.p. M. 3981–2.

1070. Spring wheel chain drive. Presented by Messrs. Hans Renold, Ltd., 1911.

In order to permit the application of chain driving to machinery that works under a variable load, it is necessary to employ a spring wheel device which shall absorb the shocks due to the fluctuations of load, and so prevent them from damaging the chain. Such drives are successfully applied to air and water pumps, rolling mills, forging machines, &c.

The spring wheel shown consists of an inner hub or boss keyed to the driven shaft, and an outer rim on which the teeth are cut. The chain rim is free to turn on the boss, through a small angle, and is connected with it by two sets of helical springs of unequal strength placed between lugs formed on the hub and rim. The stronger springs, working in compression, transmit the driving load and act as a cushion, while the weaker springs act as buffers against the rebound of the others. A cover plate is fitted to the rim and forms a side bearing on the boss.

The chain shown is of the liner silent type (*see* No. 1069), 1 in. pitch, 2·2 in. wide, breaking load 10,400 lb., weight 4·25 lb. per ft., to transmit 12 h.p. It is mounted on a 44-tooth spring wheel with a central guiding groove, and a 17-tooth pinion which rotates at 900 rev. per min., giving a chain speed of 1,275 ft. per min. M.3985.

1071. Chain-driven gear-box for motor omnibus. Lent by the Coventry Chain Co., Ltd., 1912.

This form of change speed gear-box, in which noiseless chains are used instead of spur wheels to connect the main with the countershaft, was patented by Mr. F. Searle in 1910. The example shown transmits 30 h.p., and represents that used by the London General Omnibus Company in their "B" type of motor omnibus (*see* No. 179), where they have proved very successful, being efficient, silent, and able to withstand rough handling.

The gear gives three forward speeds by means of three chains and a reverse by a pair of spur wheels; a direct drive is obtained on the highest speed. The driving and driven shafts are in line with one another, and the countershaft is mounted beside them; the box is divided into two compartments by a partition, and all the shafts run on ball bearings. In the first compartment the driving shaft terminates just within the gear-box, where it carries a chain pinion with clutch jaws formed on it; the countershaft carries

two fixed pinions, while the inner end of the driven shaft carries a loose pinion also provided with clutch jaws. Two chains connect these pinions in pairs, and a sliding clutch keyed on the end of the driven shaft connects either the driven shaft to the driving shaft, giving the direct drive, or the loose pinion to the driven shaft, giving the second speed through the first two chains. In the second compartment the driven shaft carries a fixed chain wheel and a spur wheel close to the end of the gear-box; the countershaft carries a loose chain pinion, connected by a chain with the driven shaft wheel and a sliding clutch having a spur pinion formed with it. This clutch is keyed to the countershaft, and, when engaged with the chain pinion, gives the third speed through the first and third chains, but when pushed in the opposite direction causes the spur wheels to engage and so give the reverse. The clutches are moved by two rods through a lever and gate quadrant. All the chains are running whichever speed is employed, it being found, in practice, unnecessary to stop the countershaft when on the high speed, or to provide for adjustment of the chains.

The chains used are of the noiseless or toothed type (*see* No. 1068), with outside guide plates. The link plates are punched from sheet steel, and are held together in pairs by hardened steel bushes that turn on the connecting rivets. The first chain is 0·75 in. pitch and 2·54 in. wide, the second is 0·625 in. pitch and 2·03 in. wide, and the third is 0·75 in. pitch and 3 in. wide; the distance between the shaft centres is 6 in. The driving shaft runs at 1,000 rev. per min., and the second and third speeds reduce this to 600 and 267 rev. per min. respectively. M.4026.

1072. Ratchet driving gear. Presented by E. W. Coleman, Esq., 1911.

This mechanism was one of the earliest devised for converting a reciprocating motion into a continuous rotary motion; it was applied in 1770 by Cugnot to his traction engine (*see* No. 159), and by Symington to his steamboat engine of 1788 (*see* Marine Engineering Collection). The modern construction shown, however, was patented by Mr. Coleman in 1906, and is used for driving light machinery by hand or foot power.

The mechanism consists of a bent lever, having two pitch chains attached to it at points on opposite sides of its fulcrum; these chains pass over the chain wheels of two ordinary free-wheel clutches, as used on bicycles, and their other ends are attached to springs which keep them in tension. The clutches are fixed on the shaft to be driven, and the chains are passed round so that one of them drives on each stroke of the lever, and the motion of the shaft is continuous. The pull of the chains being always tangential to the clutch wheels there are no dead centres. M.3826.

Fluid Pressure Transmission.

1073. Model of hydraulic accumulator. (Scale 1 : 16.) Made in the Museum Workshop, 1900. Plate XII., No. 7.

This represents a modern form of the accumulator invented by Lord Armstrong in 1851, and shows one of a pair used in the hydraulic power supply of Birmingham.

The accumulator has a cast iron cylinder, with a ram 18 in. diam. by 20 ft. stroke, and is connected with the 6 in. hydraulic mains by a 5 in. pipe. The ram is loaded to 730 lb. per sq. in. by 84 tons of puddling-furnace cinder contained in an annular wrought iron casing 9·8 ft. diam. by 20·24 ft. long, suspended from the cross-head by bolts, and guided by cast iron blocks sliding between angle irons secured to vertical timbers.

One accumulator is loaded with about 2·5 tons less than its neighbour, and its ram therefore rises first, till stopped by four long tie-bars hanging from it, provided with nuts, which come into contact with heavy lugs on the cylinder.

The other accumulator then rises, and, when within 3 ft. of the top of its travel, moves a tappet on a vertical rod which throws over a lever opening a by-pass between the suction and discharge valves of the first of three hydraulic pumps. After 1·5 ft. more lift, the second pump is thrown out of action, and at 1·5 ft. higher, or the full stroke, the third pump is stopped. To guard further against over-pumping, a casting on the casing lifts a 2·5 in. relief valve, but if the motion should still continue grooves cut in the bottom of the ram come through the stuffing box and so allow water to escape. The total energy stored in the two accumulators is 3·7 h.p. hours.

The hydraulic pumps are driven by belting from three gas engines, one giving 25 and the other two 50 indicated h.p. each, at 160 rev. per min.; the exhaust is deadened by passing through iron pipes in a brick flue to the base of a chimney, 50 ft. high, where it is discharged through a series of pipes 1·5 in. diam. and 3 to 7 ft. long. The pumps have each three plungers 3 in. diam. by 12 in. stroke, and 2·5 in. diam. by 10 in. stroke respectively, and their crankshaft makes 49 rev. per min.; part of the suction water is drawn through the gas engine jackets as cooling water. A 2 h.p. three-cylinder hydraulic engine is provided for starting the gas engines. M.3135.

See "Engineering," 1892, I., p. 254.

1074. Diagrams relating to the distribution of hydraulic power in London. Lent by E. B. Ellington, Esq., 1891.

The water is supplied at a guaranteed pressure of not less than 700 lb. per sq. in.; where a considerably higher pressure is desired a hydraulic intensifier is employed by the consumer to deliver a proportionately less quantity of water at the required pressure. The intensifier represented is for delivering water at a pressure of 4,500 lb. per sq. in. into a press for squirting lead pipe. It consists of an upper cylinder fixed on columns and fitted with a ram 15·5 in. diam. by 13 ft. stroke; at the base is fixed a ram of 6 in. diam., and upon this the upper ram, which serves also as a cylinder, can travel. By the hand valve shown, water at 700 lb. is first admitted to the small ram, so causing the large one to rise to the top of its travel; a lever is then moved closing the supply to the small ram and admitting it to the large one, which is thus forced downward, the water within it being at the same time expelled to the lead press.

The large stop valves on the power mains are, owing to the pressures involved, of the compound type shown, having a small internal valve and an equilibrium cylinder controlled by it, so that the labour of opening the largs valve is reduced to that necessary for manipulating the small one. On each side of the main valve is a spring-loaded "momentum valve," by which serious concussion upon sudden closing is prevented. The arrangement consists of a plunger pressed home by a powerful spring, so adjusted that the arrested momentum of the water column is absorbed in forcing the plunger outward; after the energy has thus been stored in the spring the plunger returns it to the main.

The cast iron mains are connected by oval flanged joints, the lugs of which were at first rather liable to be broken off, but this defect was overcome by placing them further from the end, as shown in the drawings.

M.2384.

RECENT ACQUISITIONS.

A number of objects that have been received since the date of the last edition of this Catalogue have not been fully described, owing to the absence of many of the staff on war duties.

The short titles of such objects are entered here, with the serial numbers indicating their correct position in the Catalogue.

15A. Photograph of engraving of Barker's mill, 1767.
Inv. 1915—318.

15B. Whitelaw reaction turbine.
Inv. 1914—898.

24A. Bamford hydraulic engine. Presented by S. J. Ambler, Esq.
Inv. 1914—139.

29A. Hydraulic swash-plate engine. Made by Messrs. Sir W. G. Armstrong, Whitworth & Co.
Inv. 1914—676.

50A. Photographs (28) of atmospheric engine at Pentrich Colliery. Presented by W. T. Anderson, Esq.
Inv. 1917—34.

127A. Dog-crank engine.
Inv. 1913—304.

158A. Prints of Ljüngstrom steam turbine.
Inv. 1915—25.

179A & B. Photographs and prints of Butler's petrol cycle, 1888—9. Presented by E. Butler, Esq.
Inv. 1915—403 & 404.

200A. Engraving of locomotive "Northumbrian."
Inv. 1914—290.

320A. Albion-Murray aero-engine lubricator. Presented by the Albion Motor Car Co., Ltd.
Inv. 1919—234.

336A & B. S.E.A. piston and piston rod packings. Presented by Messrs. Ronald Trist & Co., Ltd.
Inv. 1914—193 & 194.

358A. Model of Lancashire boiler. (Scale 1 : 12.) Lent by Lt.-Col. J. D. K. Restler.
Inv. 1918—197.

375A. Reproduction of ancient Roman water heater.
Inv. 1914—406.

395A. Thermofeed regulator. Made by Messrs. Ronald Trist & Co., Ltd.
Inv. 1914—192.

421A. "Little Scorcher" steam separator. Presented by Messrs. Princeps & Co.
Inv. 1914—117.

422A. Carbon dioxide thermoscope. Presented by the Underfeed Stoker Co , Ltd.

Inv. 1914—223.

429A. Robinson hot air engine. Presented by Messrs. A. E. & H. Robinson.

Inv. 1914—657.

441A. Spray-makers for Priestman oil engine. Lent by Messrs. Priestman Bros., Ltd.

Inv. 1914—407 & 408.

450A. Motor unit for bicycles. Presented by Messrs. Motosacoche Ltd.

Inv. 1915—183.

452A. Two-and-a-half H.P. motor cycle engine. Presented by Messrs. Motosacoche Ltd.

Inv. 1915—182.

469A. Photograph of Benz sparking plug, 1888.

Inv. 1915—66.

478A. Hand revolution counter.

Inv. 1914—287.

478B. Combined revolution counter and stop watch.

Inv. 1914—288.

480A. Schæffer and Budenberg reciprocating counter.

Inv. 1914—286.

481A. Harding's revolution counter.

Inv. 1914—285.

485A. Sir J. Whitworth's millionth measuring machine, 1855. Lent by Sir W. G. Armstrong, Whitworth & Co., Ltd.

Inv. 1919—265.

491A. Set of Whitworth end gauges, 1 in. to 12 in.

Inv. 1915—288.

499A. Minimeter. Presented by F. Holden, Esq.

Inv. 1919—252.

499B. Fluid gauge. Lent by Messrs. J. A. Prestwich & Co., Ltd.

Inv. 1919—251.

499C. to F. Vernier depth gauge. Machine divided steel scales. Centre gauges 55° and 60°. 8 in. engineer's steel square. Lent by J. Chesterman & Co., Ltd.

Inv. 1919—253-256.

499G. Surface plate. Lent by H. M. Budgett, Esq.

Inv. 1919—258.

528A. Reproduction of ancient Roman bronze steelyard.

Inv. 1914—404.

528B. Reproduction of ancient Roman bronze balance.

Inv. 1914—405.

541A & B. Torsion balances. Presented by the Torsion Balance Co.

Inv. 1915—43 & 44.

548A & B. Vortex speed indicators. Presented by Killingworth Hedges, Esq.

Inv. 1915—560 & 561.

557A. Accelerometer. Presented by H. E. Wimperis, Esq.
Inv. 1914—236.

601A. Perry's original optical diaphragm indicator. Lent by The Finsbury Technical College.
Inv. 1915—167.

615A & B. Photographs of pumping engines used at the Thames Tunnel. Presented by the East London Railway Co.
Inv. 1915—323 & 325.

711A. Water taps. Presented by F. Ward, Esq.
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724A. Model of Shand, Mason's steam fire engine. (Scale about 1 : 5.) Lent by Lt.-Col. J. D. K. Restler.
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737A. Photograph of post-chaise.
Inv. 1914—208.

742A & B. Model of a London omnibus, 1855 (Scale about 1 : 20), and model of a hansom cab, 1855 (Scale about 1 : 30). Bequeathed by E. Earnshaw, Esq.
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774A. McCammon's safety bicycle, 1884. Presented by P. A. Newton, Esq.
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778A. "Xtraordinary" bicycle. Presented by Messrs. Singer & Co., Ltd.
Inv. 1916—75.

819A. Cast iron plate rails and stone steepers from the Cinderford Tramway, 1825-1848. Presented by the Great Western Railway Co.
Inv. 1915—184.

835A. Sections of rails used on the Great Western Railway, 1840–1900. Presented by J. E. Goldwyer, Esq.
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848A. Section of broad gauge permanent way. Presented by the Great Western Railway Co.
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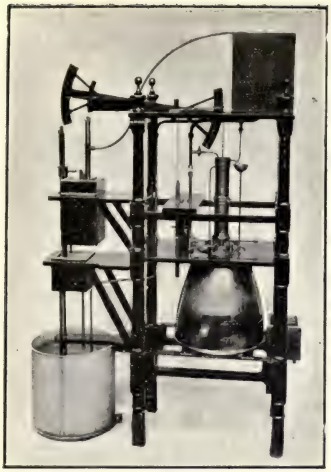
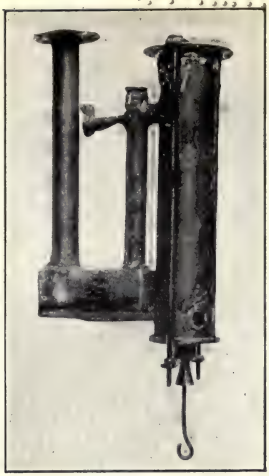
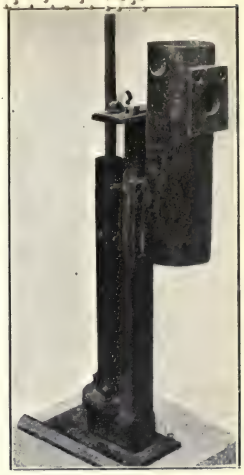


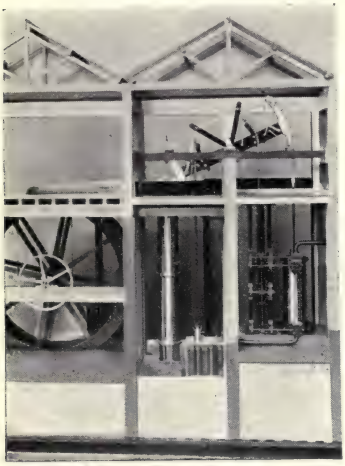
1. Newcomen engine, p. 29.



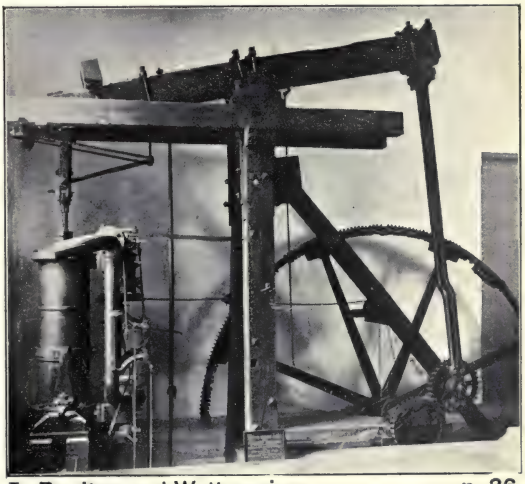
2. Separate condenser, p. 31.



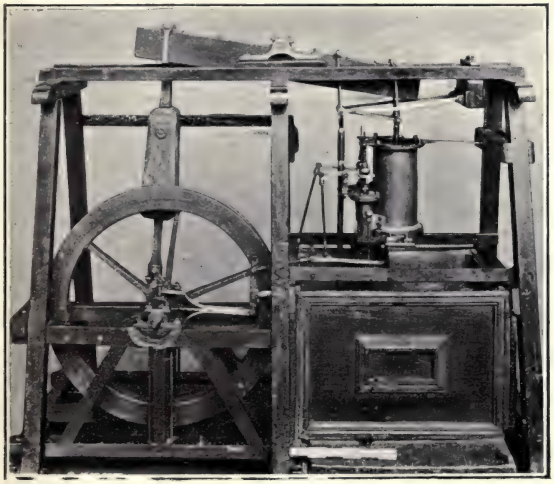
3. Surface condenser, p. 32.



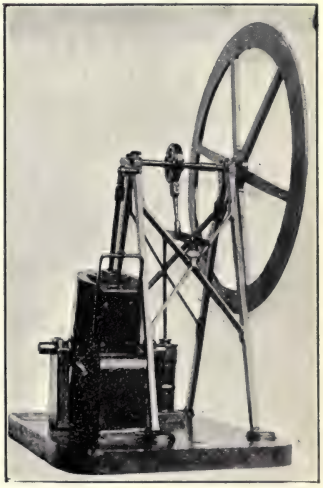
4. "Old Bess" engine, p. 33.



5. Boulton and Watt engine, p. 36.



6. Single-acting rotative engine, p. 38.



7. Oscillating engine, p. 40.

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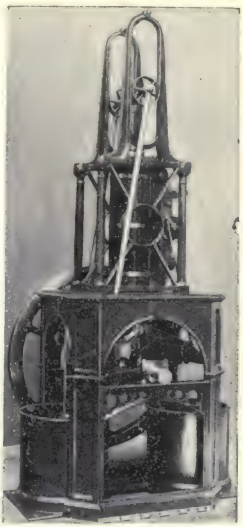
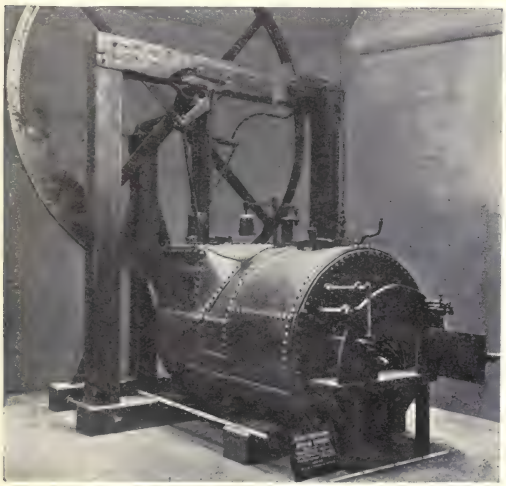
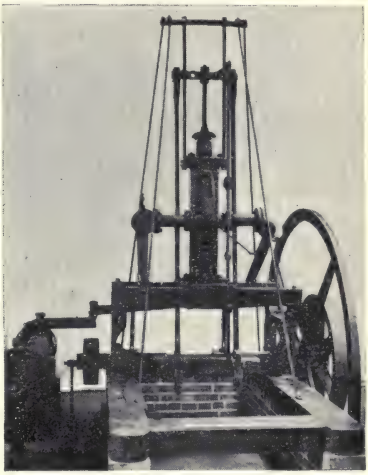
1. Heslop's beam engine, p. 44.



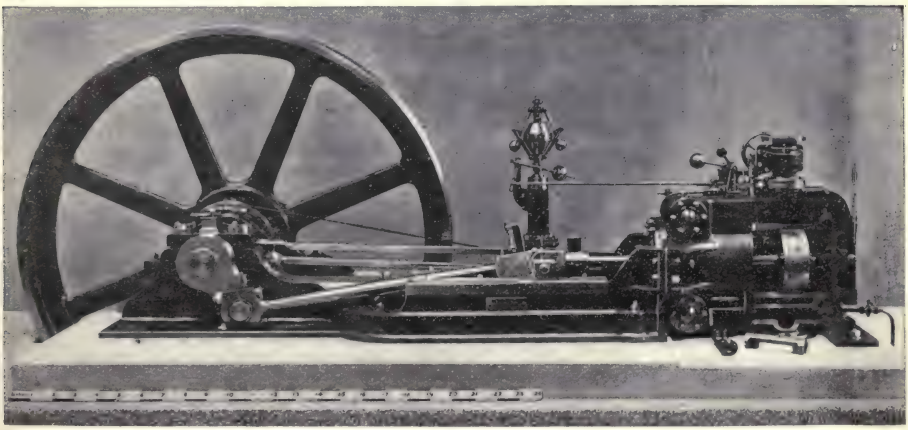
2. Table engine, p. 47.



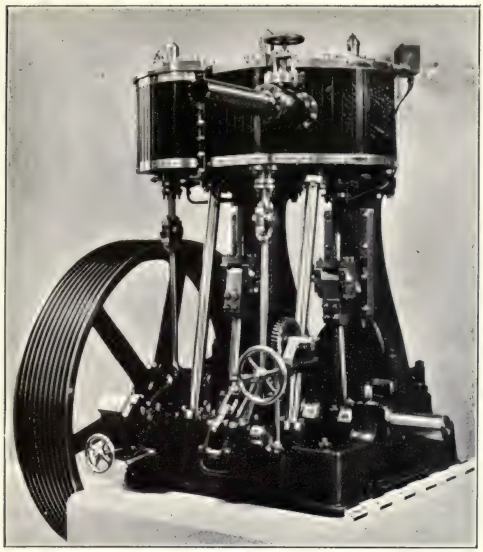
3. Trevithick's engine, p. 48.



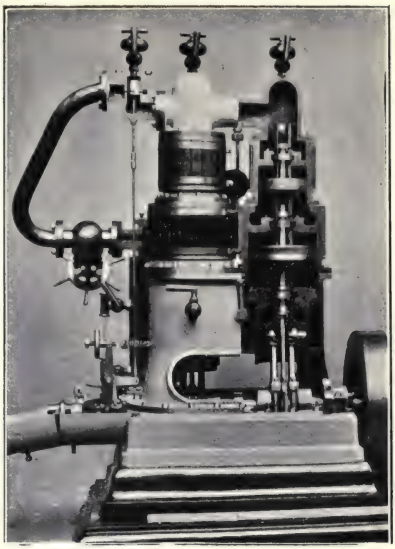
4. Early vertical engine, p. 48.



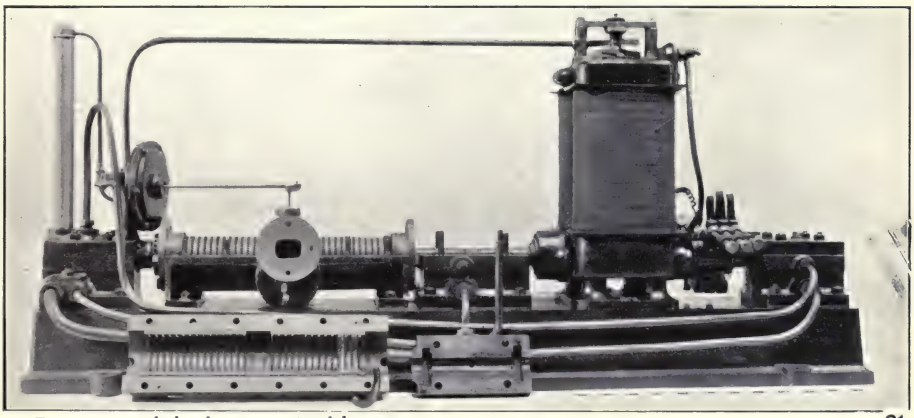
5. Mill engine, with Corliss valve gear, p. 54.



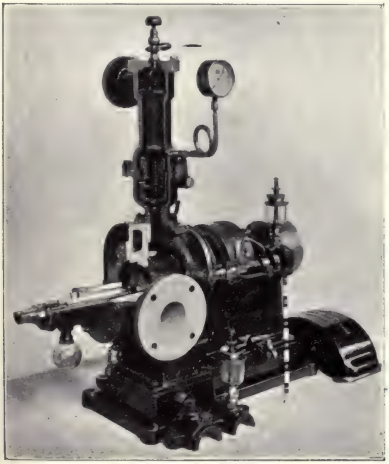
1. Vertical compound engine, p. 55.



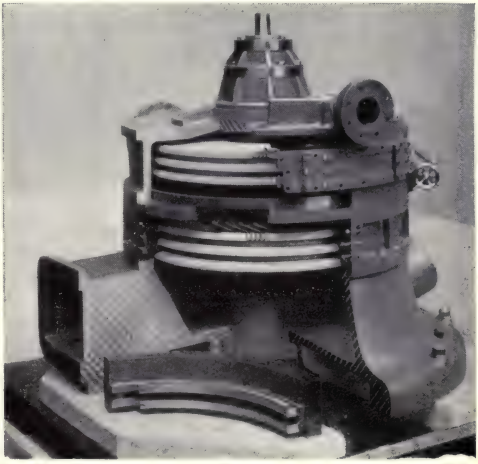
2. Willans engine, p. 56.



3. Parsons original steam turbine, p. 61.



4. De Laval steam turbine, p. 62.



5. Curtis steam turbine, p. 63.

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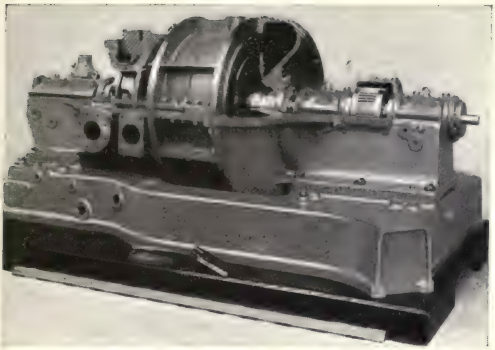
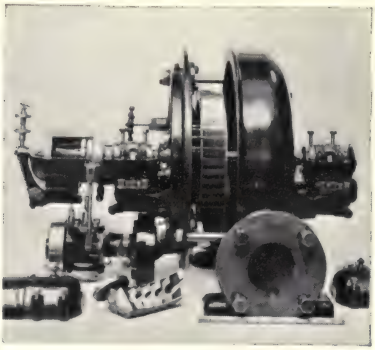
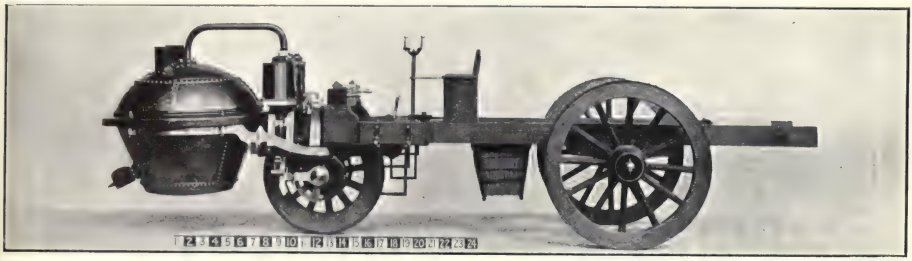


1. Rateau steam turbine, p. 64.

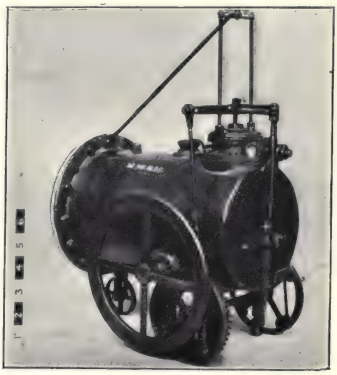


2. Sturtevant steam turbine, p. 68.

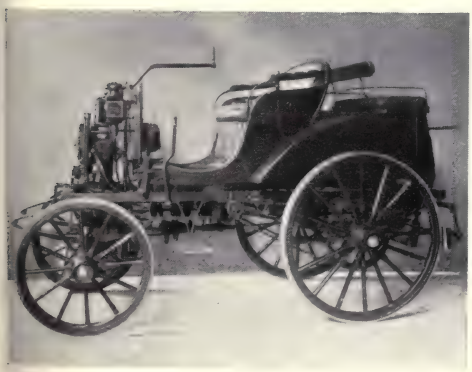


3. Cugnot's traction engine, p. 71.

4. Murdock's locomotive, p. 72.



5. Trevithick's locomotive, p. 72.



6. Panhard motor car, p. 79.

7. Benz motor car, p. 80.

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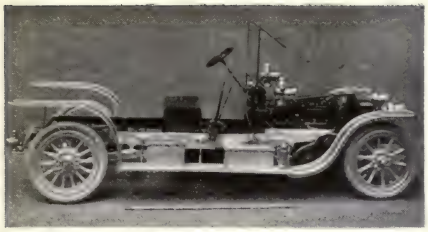
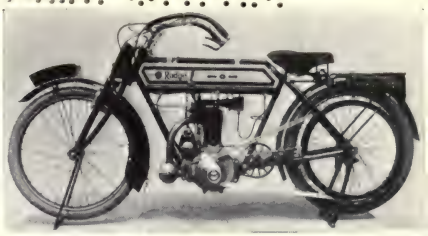
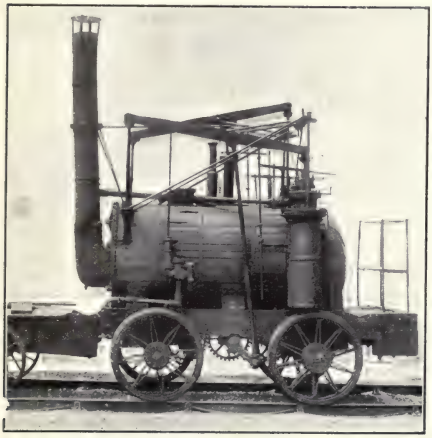


1. Rolls-Royce motor car, p. 83.

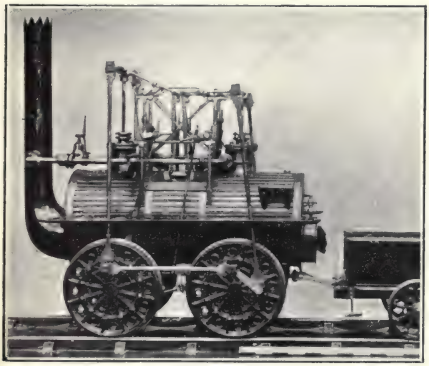


2. Rudge motor cycle, p. 85



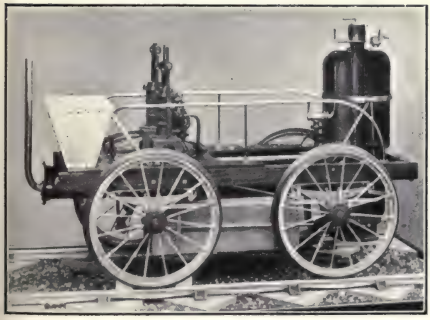
3. "Puffing Billy" locomotive, p. 93.

6. "Rocket" locomotive, p. 97.



4. "Locomotion" locomotive, p. 95.

7. "Sans Pareil" locomotive, p. 99.



5. "Novelty" locomotive, p.101.

8. Bury locomotive, p. 113.

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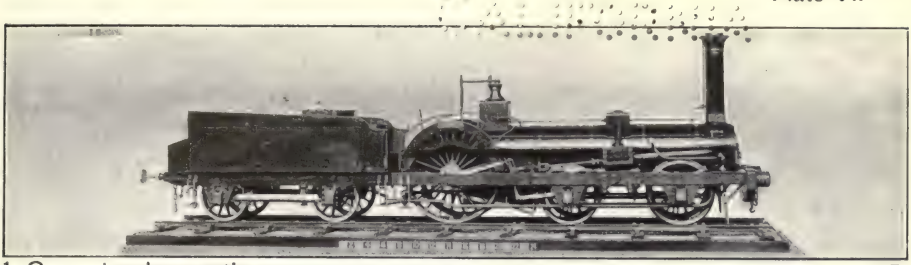
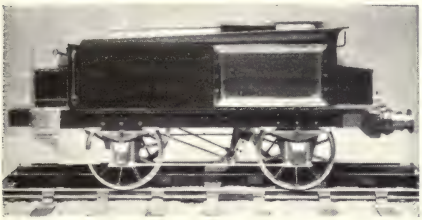
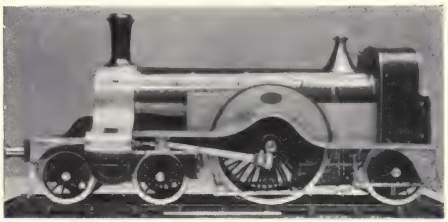


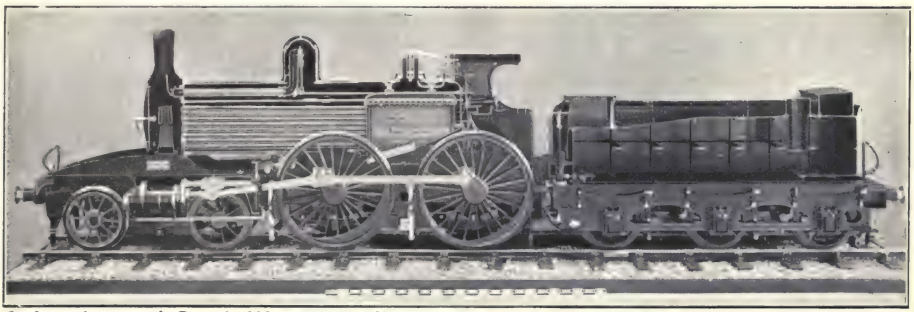
1. Crampton locomotive, p. 115.



2. Water scoop tender, p. 133.

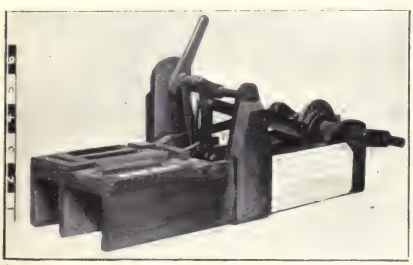


3. G.N.R. locomotive, p. 119.

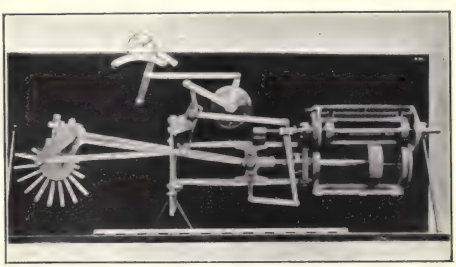


4. London and South Western Railway locomotive, p. 123.

5. Western Railway of France locomotive, p. 126.



6. Howe's link motion, p. 144.



7. Walschaerts valve gear, p. 145.

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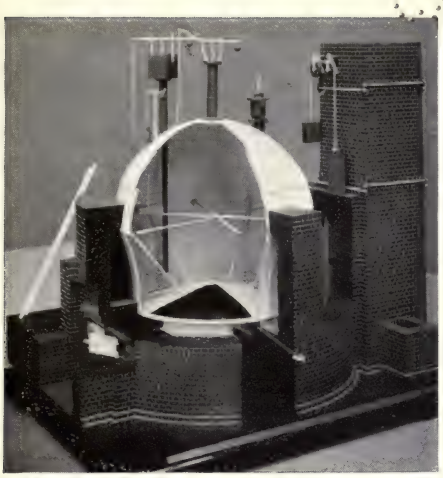
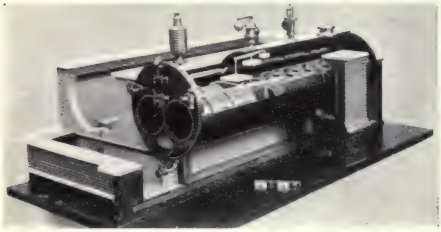
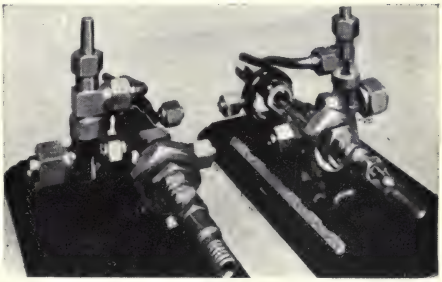


1. Haystack boiler, p. 171.

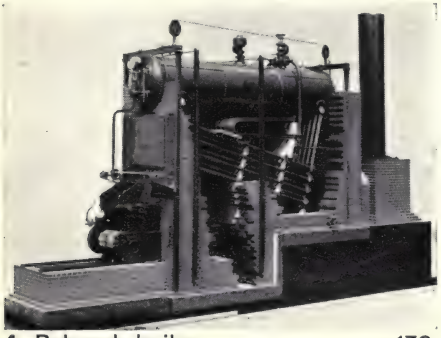
2. Wagon boiler, p. 172.



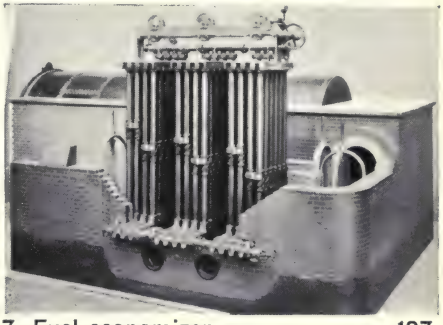
3. Galloway boiler, p. 175.



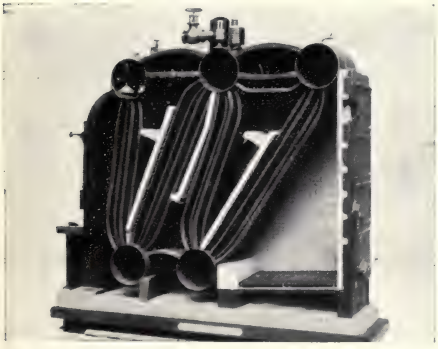
6. Holden's liquid fuel burner, p. 191.



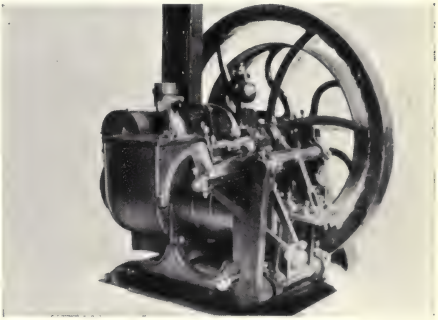
4. Babcock boiler, p. 179.



7. Fuel economizer, p. 197.



5. Stirling boiler, p. 180.



8. Ericsson's caloric engine, p. 207.

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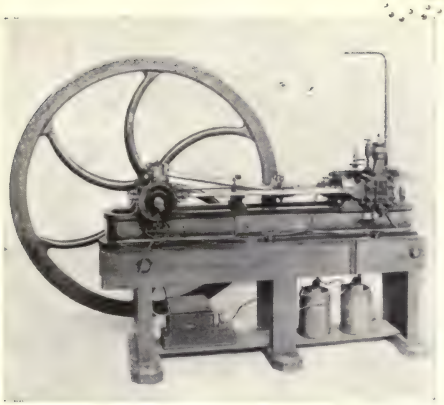
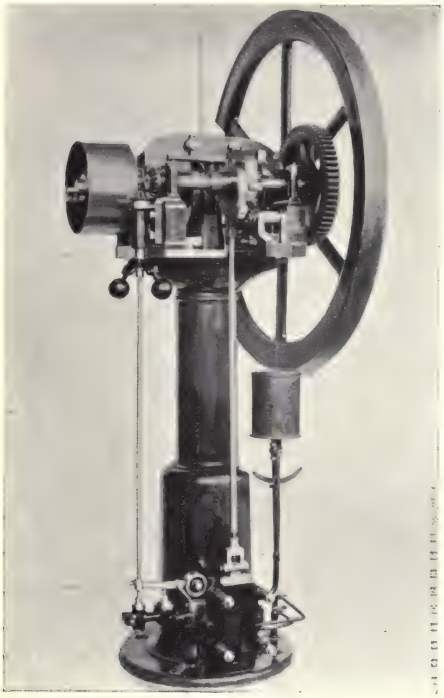
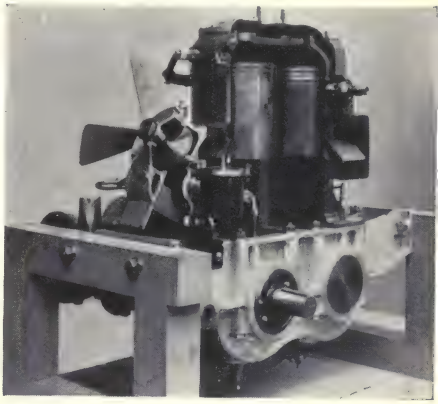


1. Lenoir gas engine, p. 209.

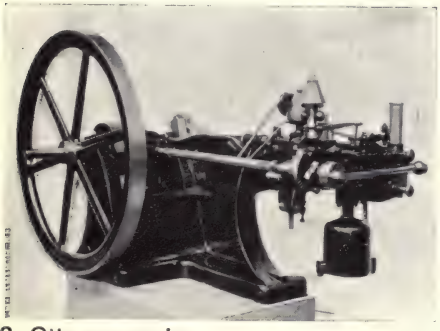
4. Petrol motor, p. 216.



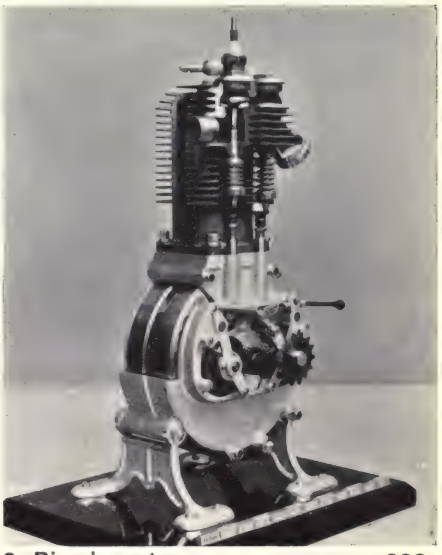
2. Atmospheric gas engine, p. 210.



5. Lucas two-stroke motor, p. 219.



3. Otto gas engine, p. 211.



6. Bicycle motor, p. 220.

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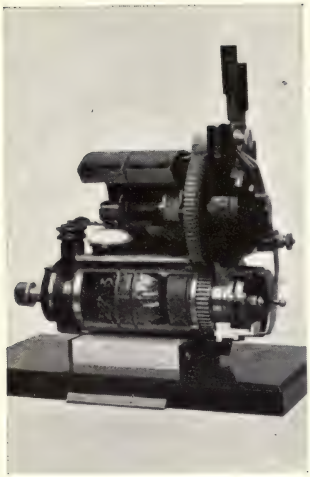
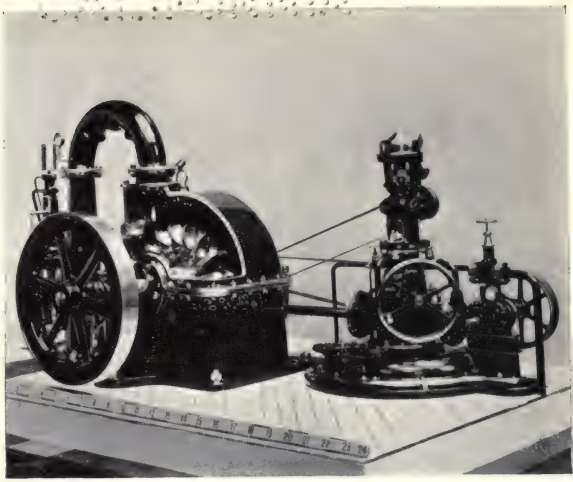
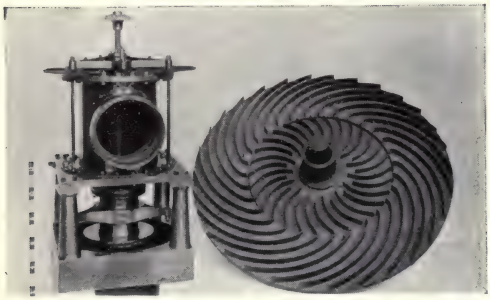


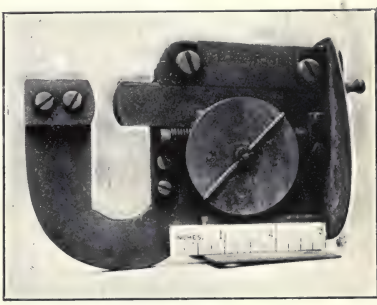
1. Ignition magneto, p. 228.



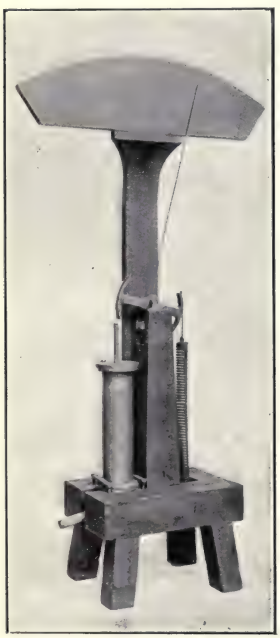
2. Pelton wheel, p. 13.



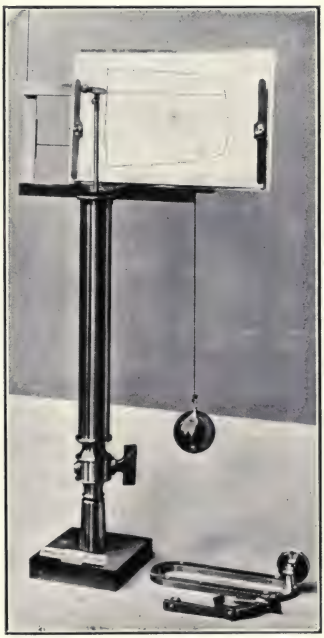
3. Fourneyron turbine, p. 13.



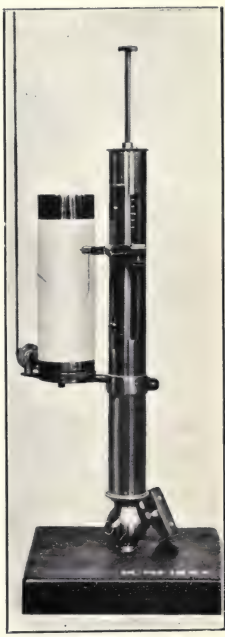
4. Watt's micrometer, p. 237.



5. Vacuum indicator, p. 261.



6. Watt's indicator, p. 269.



7. McNaught indicator, p. 270

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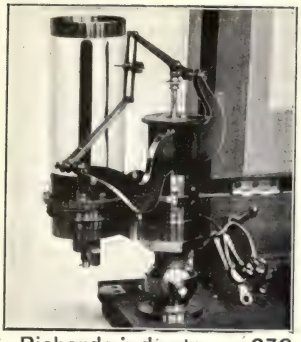
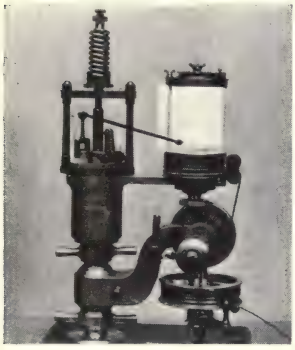
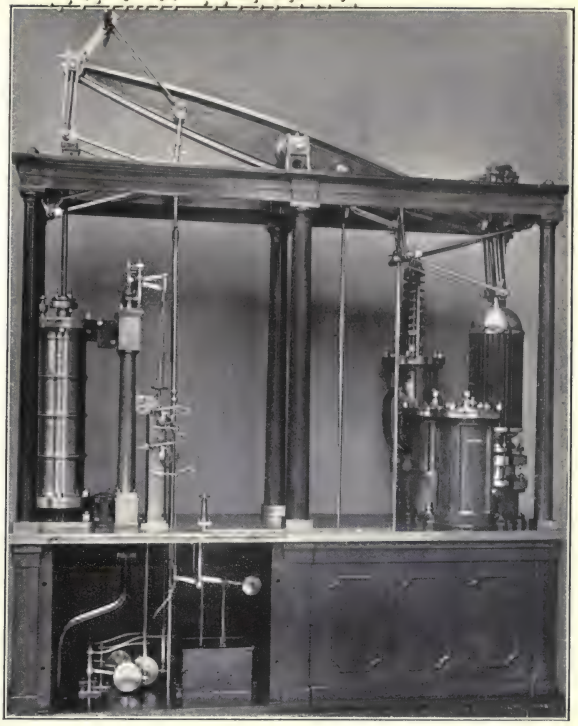


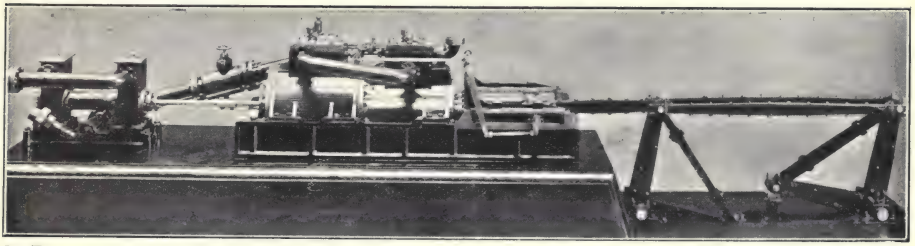
1. Richards indicator, p 270.



2. Crosby indicator, p. 273.

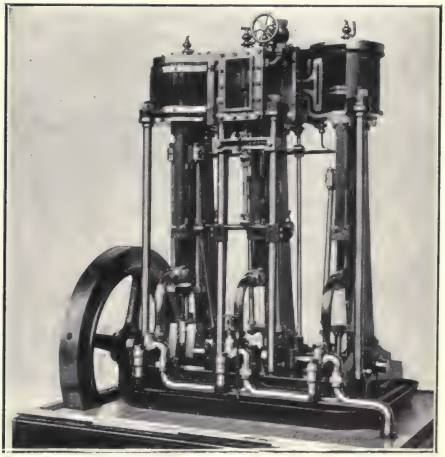


3. Cornish pumping engine, p. 282.

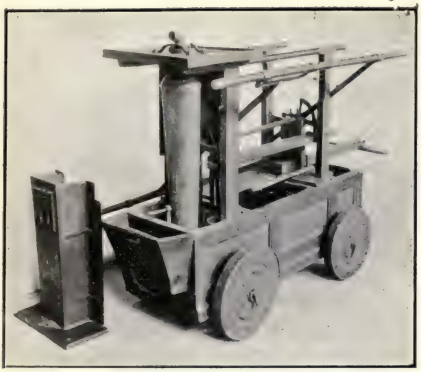


4. Davey compound pumping engine, p. 285.

5. Bramah's hydraulic press, p. 293.

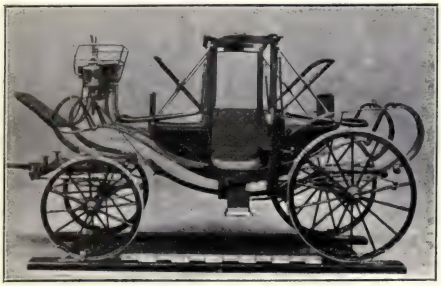


6. Hydraulic pumping engine, p. 294.



1. Manual fire engine, p. 322.

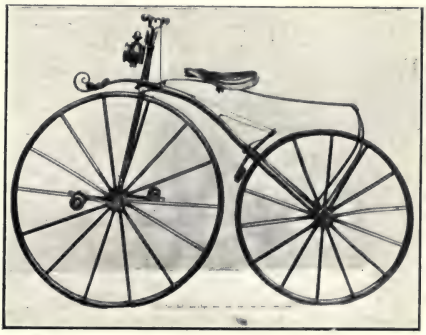
2. Steam fire engine, p. 324.



3. Landau, p. 334.

5. Macmillan bicycle, p. 342.

4. Hobby horse, p. 341.



6. "Boneshaker," bicycle, p. 342.

7. Jessop's edge rails, p. 362.

8. Plate rails, p. 362.

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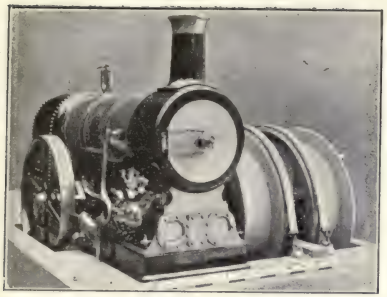
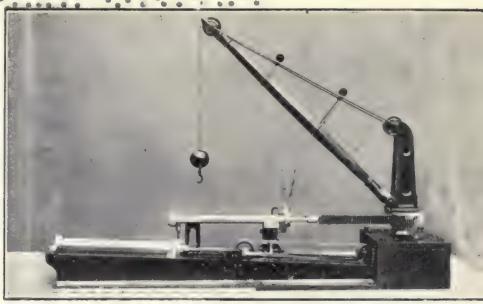
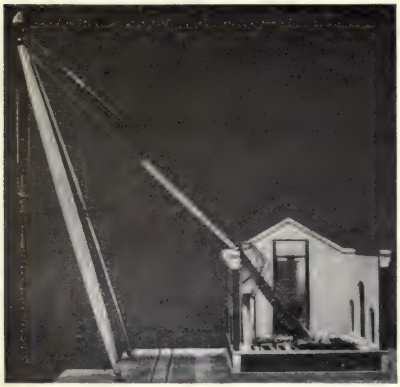


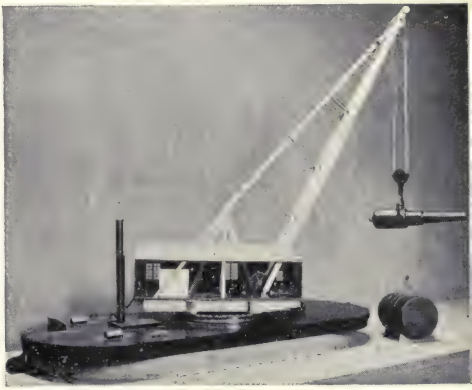
1. Winding engine, p. 422.



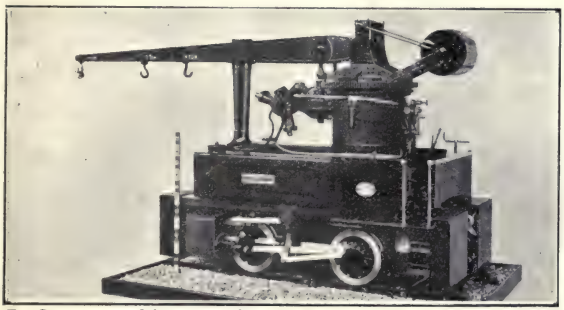
2. Armstrong crane, p. 424.



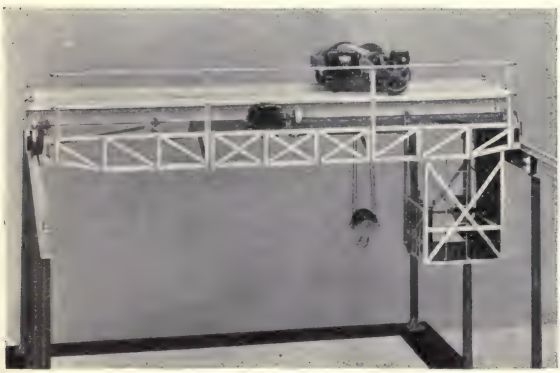
3. Hydraulic sheer legs, p. 426.



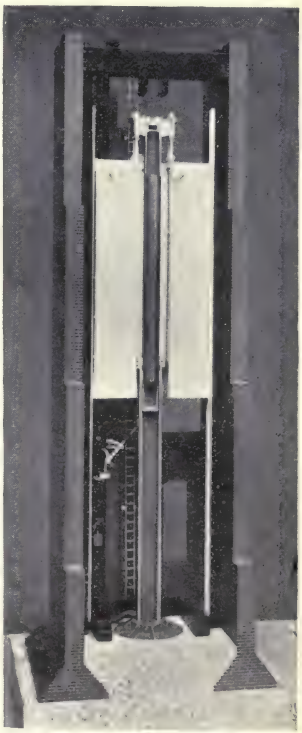
4. Floating crane, p. 430.



5. Crane and locomotive, p. 428.



6. Overhead travelling crane, p. 429.



7. Accumulator, p. 458.

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